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THE VIRGINIA JOURNAL OF SCIENCE

VOL. 2, NEW SERIES JULY, 1951 NO. 3

A Significance Test for Differences Between Ranked Treatments In an Analysis of Variance[1]

D. B. DUNCAN

University of Sydney
and Virginia Agricultural Experiment Station
of the Virginia Polytechnic Institute

PREFACE

The homogeneity of a set of treatments in an analysis of variance is readily tested with an F (or z) test. The desirable features of this test are well known and may be said to come mainly from its conformance with the likelihood ratio criterion. In some cases however it falls short of practical requirements in that, when the homogeneity hypothesis is rejected, it gives no decisions as to which of the differences among the means may be considered responsible. There is a strong need for a procedure which will incorporate the desirable likelihood ratio properties of the F test and will at the same time give decisions on the relative merits of the treatments considered in all possible pairs.

Several approaches to this problem are considered and a test is presented which appears to meet the need very closely. In doing this, mathematical detail has been avoided as far as possible. A parallel discussion involving the details of a multiple choice test analysis is given separately in a companion paper by the author (1952).

Tables for tests at especially defined 5% and 1% levels are provided.

INTRODUCTION

In comparing the means (or totals) of several treatments it is often pertinent to consider them in ranked order and to ask whether each one taken in turn is "significantly" better than each of the others below it. That is, for any pair, it is asked whether it is reasonably safe to decide that the treatment with the higher observed mean has the higher population mean.

1. This and a companion paper, the latter to be published in this Journal (Vol. 3, No. 1), include and extend a thesis (1947) approved for the degree of Ph.D. at the Iowa State College.

Editor's Note: For this and a companion paper, presented at the Annual Meeting of the Academy, May 11, 1951, Mr. Duncan received the **J. Shelton Horsley Award.** This award is made annually in recognition of the "most highly meritorious paper" presented at the Annual Meeting.

Our problem is to provide a test for this purpose under conditions which usually apply or are taken to apply in many analyses of variance, namely, the treatment means, $x_1, x_2, \ldots, x_n$, are a random sample from n normal populations with means $\mu_1, \mu_2, \ldots, \mu_n$ respectively and a common unknown variance σ^2, and this population variance is estimated independently by an observed variance s^2 based on n_2 degrees of freedom.

Example 1: Sears tested the yields of eleven pasture mixtures in a 4x11 randomized block design at the Virginia Polytechnic Institute in 1949. The means arranged in order are:

F	K	D	E	A	J	B	G	C	H	I
2.85	3.60	3.94	4.05	4.55	4.96	5.03	5.41	5.96	6.09	6.97

The analysis of variance is:

Source	d/f	s.s.	m.s.
Blocks	3	.8043	.2681
Treatments	10	58.8802	5.8880
Error	30	13.8414	.4614

and from this the variance of a treatment mean is $s^2 = .11535$ based on $n_2 = 30$ degrees of freedom.

Nothing is assumed to be known *a priori* about the relative rankings of the treatments. Having observed the results, it is required to test whether I is significantly better than F, K, . . . up to H, whether H is significantly better than F, K, . . . up to C, and so on. This is a typical example of the general problem.

In the simple two-treatment case, $n = 2$, the problem is perfectly solved in a very familiar way by using an α-level two-sided t test of the null hypothesis $H_0: \mu_1 = \mu_2$. In this procedure, if $(x_1 - x_2)/\sqrt{2}\, s > t_\alpha$, the appropriate α-level significant value of t, we decide that x_1 is significantly larger than x_2, or in other words we accept the alternative hypothesis $H_1: \mu_i > \mu_j$, for i,j = 1,2 or 2,1. If $(x_1 - x_2)/\sqrt{2}\, s \not> t_\alpha$ we say that x_1 is not significantly greater than x_2 or that we do not accept $H_1: \mu_1 > \mu_2$.

In the more complex cases with several treatments $n > 2$, it is natural at first to attempt to solve the problem by applying α-level two-sided t tests to each of the ${}_nC_2$ null hypotheses $H_0: \mu_i = \mu_j$ that can be obtained by considering the treatments in all possible pairs. The joint test obtained in this way would consist of the rule: If $(x_1 - x_2)/\sqrt{2}\, s > t_\alpha$ accept $H_1: \mu_i > \mu_j$, otherwise do not accept $H_1: \mu_i > \mu_j$ for all ${}_nP_2$ permutations of the means. This we may refer

to henceforth as an α-level multiple t test.

Many of the standard texts[2] give warnings against the use of this test and it is widely realized that it has most unsatisfactory features. Its most obvious defect is the large error probability of wrongly rejecting the hypothesis that all of the n treatments concerned are homogenous. It can be shown that a 5% level multiple t test (with $n_2 \to \infty$), for example, has error probabilities of this nature as high as 12.23% in the case of three treatments, 20.34% for four treatments, and so on up to as much as 91.83% for 20 treatments. While it can be, and will be, argued that these errors do not have to be as low as the chosen 5% value, they are far too large to be satisfactory.

What is required in effect is a test for the general case $n > 2$ which achieves the excellent properties of an α-level two-sided test in the case $n = 2$, as the α-level multiple t test attempts to do, but which does not fall into the same difficulties.

PAST AND PRESENT TEST PROCEDURES

A brief illustrated review of some of the tests proposed in the past will serve to introduce the general problem further and will provide a useful background for the main ideas to be put forward.

The first of these is one that has enjoyed considerable use in the past and consists of applying a multiple t test if and only if the null hypothesis $H_0: \mu_1 = \mu_2 = \ldots = \mu_n$ is first rejected by means of an F test. If the F test is not significant all differences among the means are concluded to be not significant without any further testing.[3]

The results of this procedure are often presented in the form of an α-level least-significant difference, $\sqrt{2}\, st_\alpha$, placed at the foot of a table of ranked means, and it is thus often termed the least-significant difference test.

Example 2: The F value for between treatments in the pasture data in example 1 is 12.76 and is significant relative to the 5% significant value, 2.16. This allows the use of the 5% least significant difference $\sqrt{2}\, st = .98$. From this we conclude that all pairs of means not appearing together in a common bracket in the following table differ significantly from one another.

F	K	D	E	A	J	B	G	C	H	I
2.85	3.60	3.94	4.05	4.55	4.96	5.03	5.41	5.96	6.09	6.97

2. For example, Tippett (1937) section 3.33, Fisher (1947) section 24, Snedecor (1946) section 15.5, Paterson (1939) p. 38, and Cochran and Cox (1950) section 3.53.

3. The idea of using an F test in this way was first suggested by Fisher loc. cit. Others have followed this up by giving the above test in detail, e.g., Paterson (1939) pp. 38-42, Goulden (1939) example 33, p. 149, Love (1936) pp. 354-359, and Davies (1949) section 5.28.

The second test is one which D. Newman (1939) tells was first suggested by "Student" to E. S. Pearson, and which Newman developed by working approximate integrals of the studentized range. This procedure consists of applying studentized range tests, first to the range of the whole sample of treatment means, then if this is significant, to the ranges of the two subsamples obtained by eliminating the highest and lowest means respectively, then if these are significant, to the ranges of the four subsamples obtained by the elimination of their extremes and so on. The reduction process terminates for any group of means when its range is found to be not significant.

Example 3: The 5% level studentized range significant values for $n_s = 30$ degrees of freedom and sample sizes 2 to 11 are:[4]

n	2	3	4	5	6	7	8	9	10	11
q	2.89	3.52	3.85	4.10	4.31	4.47	4.61	4.73	4.83	4.92

On multiplying each of these by s = .3396 we obtain the following least significant range values:

n	2	3	4	5	6	7	8	9	10	11
ranges	.98	1.20	1.31	1.39	1.46	1.52	1.57	1.61	1.64	1.67

The results of applying these to the foregoing pasture data are:

F K D E A J B G C H I

2.85 3.60 3.94 4.05 4.55 4.96 5.03 5.41 5.96 6.09 6.97

where the brackets have the same connotation as previously in example 2.

A third test is one given by J. W. Tukey (1949) consisting of a combination of gap, extreme deviate and variance tests. This procedure will be well known to most readers. The results of applying it at the 5% level to the above pasture data are as displayed in example 4.

Example 4:

F K D E A J B G C H I

2.85 3.60 3.94 4.05 4.55 4.96 5.03 5.41 5.96 6.09 6.97

GROUP III GROUP II GROUP I

The groups differ significantly from one and another. Also significant differences are found to be present within group II but are not specified by the test.

[4] These have been obtained from Pearson and Hartley's Tables (1943).

BASIC REQUIREMENTS FOR A SATISFACTORY TEST

A full analysis of any given test involves a very detailed consideration of all of its numerous decisions and related errors and the integration of these in the form of an average weighted risk function of the type given by Wald (1939). Unfortunately the multiplicity of the decisions increases so rapidly beyond $n = 2$ and the weighting of the errors becomes so complex that this direct approach is very cumbersome for the present purposes.

From the application of the full analysis, however, there is reasonably good evidence that essentially the same results can be obtained by confining attention to a comparatively simple basic requirement. This will now be developed with fairly acceptable intuitive reasons for its justification and will be used as the main criterion of a good test in the present paper. The more analytical discussion leading to the same results is given in the companion paper by the author (1952).

In any test of the desired type we may identify a set of hypotheses of critical importance relative to the rest. First among these are ${}_nC_2$ null hypotheses of the form $H_0{:}\mu_1 = \mu_1$, stating that pairs of treatments are equal; next comes ${}_nC_3$ null hypotheses of the form $H_0{:}\mu_1 = \mu_1 = \mu_1$ stating that three treatments are equal, and so on up to one null hypothesis $H_0{:}\mu_1 = \mu_2 = , \ldots , = \mu_n$ stating that all n treatments are equal. These will be referred to as two-treatment null hypotheses, three-treatment null hypotheses and so on up to one n-treatment null hypothesis.

In association with any p-treatment null hypothesis we may define (a) a p-treatment type 1 error as the error of rejecting that hypothesis when true, and (b) a p-treatment significance level α_p as the probability of making a p-treatment type 1 error, $p = 2, 3, \ldots , n$.

When it is reflected that such a level, α_p, represents the probability of finding at least one significant difference among a set of p equal treatments, the need for a requirement along the following lines is evident:

PRELIMINARY REQUIREMENT.—For a given test T to be satisfactory its p-treatment significance levels must have suitably low upper limits. We may express this symbolically as: $\alpha_p(T) \leqslant \alpha_p$; $p = 2, 3, \ldots , n$, where $\alpha_p(T)$ represent the p-treatment significance levels of the test T, and α_p represent a set of upper limits whose values are to be discussed at length in the next section.

The main objections to an α-level multiple t test arise out of its failure to meet this requirement. It has already been pointed out that for the cases $\alpha = .05$ and $n_2 \to \infty$, α_2 (m.t.) $= .1223$, α_3(m.t.) $= .2034$, $\ldots , \alpha_{20}$(m.t.) $= .9183$, where α_n(m.t.) is used to denote the n-treatment significance level of a multiple t test. In addition to the large value for

α_n(m.t.) it will be also seen[5] that similar unduly large values occur for all of the levels α_p(m.t.), p = 3,4, . . . , n-1, within a single test. The only satisfactory levels are the two treatment ones α_2(m.t.) which equal α.

Turning now to the least significant difference test, it will be seen that the preliminary F test reduces the large value of the n treatment significance level of the multiple t test down to the level α(F) of the F test used. Thus we may write α_n(l.s.d.) = α(F). In this way the least significant difference test removes the largest of the high significance level weaknesses of the multiple t test, and, as we shall conclude later, it does this in the most acceptable way by using an F test.

Unfortunately however, the preliminary F test does nothing to insure that adequate upper limits are placed on the remaining levels α_p(l.s.d.), p = 3, 4, . . . , n-1. The lowest upper limits for these are as high as those of the multiple t test and are thus unsatisfactory. This can be illustrated in an example.

> *Example 5*: Suppose a least significant difference test is applied to u + 1 treatments, u of which are equal and the other different from the rest. It is necessary only to postulate a large enough value for the difference, and the F test is almost certain to be significant. This paves the way for the practically unconditional application of the multiple t test to the u equal treatments. Thus the least significant difference test will have the same high significance levels as those of the multiple t test with respect to this group of u treatments.

Since the arrangement of the treatment means is completely unknown a priori any α_p(l.s.d.) level can be as high as the corresponding α_p(m.t.) level, for all values of p except n.

On the other hand it will be seen that the multiple range test proposed by Newman meets this requirement completely. If we use $\alpha(q_p)$ to represent the significance level used for testing the studentized range q for a group of p means, it can be readily seen that α_p (m.q) $\leqslant \alpha\,(q_p)$; p = 2, 3, ...n-l, and α_n (m.q.) = $\alpha(q_n)$, where α_p(m. q.) denotes an α_p level of the multiple range test.

Despite this essential advantage however, this procedure has one important disadvantage relative to the least significant difference test. In starting with a range test instead of an F test it loses much appeal in the way it tests the n-treatment null hypothesis. The strong appeal of the F test for this purpose is implicit in its agreement with the

5. The levels α_p (m.t.) are readily found to given by the integral $\int_{-t\alpha}^{+t\alpha} f(q_{p,n2})\,dq$, where $f(q_{p,n2})$ denotes the distribution of the studentized range of p variates with n_2 degrees of freedom. Intregals for this distribution are given by Pearson and Hartley (1943).

likelihood ratio criterion. When an F test is used the null hypothesis has a smaller likelihood in every case in which it is rejected than in every case in which it is accepted. This is not true for a range test. For that test, the null hypothesis is sometimes rejected in cases when it has a larger likelihood than in other cases when it is accepted. This is a decided intuitive weakness of any test of a null hypothesis which does not conform to the likelihood ratio criterion.

Further consideration along these lines leads to the establishment of the main requirement:

MAIN REQUIREMENT.—For a given test T to be satisfactory, (a) it must not reject any p-treatment null hypothesis whenever the latter would not be rejected by an α_p-level likelihood ratio test, and (b) it must reject each p-treatment null hypothesis as often as is possible consistent with (a).

Relative to this requirement Tukey's method may be said to afford a compromise. It places lower limits on the various significance levels than does the least significant difference test and by including F tests it gets closer to likelihood ratio test boundaries in many situations than does Newman's multiple range test. However, it is practically impossible to determine precise upper limits for its levels and its approach to the requirement appears to be open to further improvement.

CONSISTENT SIGNIFICANCE LEVELS.

Before passing on to outline the proposed test we shall consider how low it is necessary to make the upper limits α_p, $p = 2, 3, \ldots, n$.

In his multiple range test Newman, without special comment, made these all equal to the same value .05 or .01 by using .05 level or .01 level range tests throughout. In many applications of the least significant difference test a similar step is made by putting $\alpha(F) = \alpha(\text{m.t.}) = .05$ or .01, while in others the F test level is placed at a larger value than that of the multiple t test by putting $\alpha(F) = .05$ and $\alpha(t) = .01$. In the gap, straggler and F test procedure, Tukey uses the same levels either .05 or .01 throughout.

When it is recalled that our general aim is to produce a test which has equivalent properties to that of an α-level two-sided t test in the case $n = 2$, and at the same time it is noted that the introduction of upper limits for the larger levels, α_p, $p = 3, 4, \ldots, n$, causes much relative loss of power in the tests of the two-treatment null hypotheses, it is evident that these upper limits should be relaxed as much as can be considered consistent with putting an upper limit of α on α_2.

An apparently reasonable basis for choosing a consistent set of values for these levels is given by the author (1947) and may be put as follows:

If any set of n-1 independent comparisons among n treatment means, say,

$$\theta_1 = \mu_1 - \mu_2,\ \theta_2 = \mu_1 + \mu_2 - 2\mu_3,\ \ldots,\ \theta_{n-1} = \sum_{i=1}^{n-1} \mu_i - (n-1)\mu_n,$$

were chosen a priori, and if the n-1 independent hypotheses $H_{01}:\theta_i = 0$, i = 1, 2, . . . , n-1 were each tested by n-1 independent α-level tests, the joint test so obtained would also provide tests of a full range of p-treatment null hypotheses p = 2, 3, . . . , n. For example, rejection of H_{01} or H_{02} implies the rejection of the three-treatment null hypothesis $H_0:\mu_1 = \mu_2 = \mu_3$ and acceptance of both implies its acceptance; rejection of H_{01}, H_{02}, or H_{03} implies rejection of the four-treatment null hypothesis $H_0:\mu_1 = \mu_2 = \mu_3 = \mu_4$ and acceptance of all implies its acceptance, and so on.

On consideration it is seen that the significance levels given by this joint procedure for testing p-treatment homogeneity hypotheses, are

$$\alpha_p = 1 - (1-\alpha)^{p-1};\ p = 2, 3, \ldots, n. \qquad (1)$$

Because of the independent nature of the individual tests, these levels, in this procedure at least, must be considered mutually consistent with one another. Since the p-treatment homogeneity hypotheses concerned in this test are identical in nature with, and differ only in number from those of the required test, it appears that these values, which may be usefully termed *a-per-degree-of-freedom*[6] levels provide a consistent set of upper limits for the levels under consideration.

THE MULTIPLE COMPARISONS TEST

RESTRICTED FORM.—A somewhat restricted form of the proposed test will be presented first. This consists of applying the following rule to each of the differences concerned. *Rule 1*: The difference between any two means x_i and x_j, $x_i < x_j$, is significant at the level α, provided the variance of each "p-treatment enveloping combination" of x_i and x_j is significant according to an α-per-degree-of-freedom level F test; that is, an α_p-level F test, in which the degrees of freedom for F are p-1 and n_2 respectively. (For the purpose of this rule we shall say that any combination C containing p-treatment means such that the lowest member of C is not higher than x_i and the highest member of C is not lower than x_j, is a p-treatment enveloping combination of x_i and x_j.) If any one of these variances is not significant the difference is not significant.

Fortunately, as will be seen, only very few of the F tests involved actually need to be applied. Before passing on to the application procedures it will be observed that the enveloping combinations of a difference as defined in rule 1, include every combination for which the homogeneity hypothesis would be implicitly rejected if that difference were accepted as significant. By requiring that the variance of each

6. The author is indebted for this term to a discussion with Tukey who is also using these levels in some recent unpublished extensions of his test procedure (1949).

TABLE 1.--Significant Ranges R'_{p,n_2} for a 5% Level Multiple Comparisons Test[7]

n_2 \ p	2	3	4	5	6	7	8	9	10	11	13	15	17	19	21	51	101
3	4.500	4.711	4.889	5.032	5.146	5.24	5.33	5.40	5.47	5.53	5.64	5.73	5.80	5.87	5.93	6.43	6.72
4	3.926	4.198	4.412	4.590	4.742	4.87	4.99	5.10	5.19	5.28	5.43	5.56	5.68	5.78	5.87	6.67	7.19
5	3.636	3.921	4.153	4.348	4.517	4.67	4.80	4.92	5.03	5.13	5.31	5.47	5.61	5.74	5.85	6.85	7.56
6	3.461	3.751	3.991	4.195	4.374	4.53	4.68	4.81	4.93	5.04	5.24	5.41	5.57	5.71	5.84	6.99	7.85
7	3.345	3.637	3.880	4.090	4.274	4.44	4.59	4.73	4.85	4.97	5.18	5.37	5.54	5.69	5.83	7.11	8.09
8	3.261	3.554	3.800	4.013	4.201	4.37	4.52	4.67	4.80	4.92	5.14	5.34	5.51	5.68	5.82	7.21	8.30
9	3.199	3.492	3.739	3.955	4.145	4.32	4.48	4.62	4.76	4.88	5.11	5.31	5.50	5.67	5.82	7.30	8.48
10	3.151	3.444	3.691	3.908	4.101	4.28	4.44	4.58	4.72	4.85	5.08	5.30	5.48	5.66	5.82	7.37	8.63
11	3.113	3.405	3.653	3.871	4.065	4.24	4.40	4.55	4.69	4.82	5.06	5.28	5.48	5.65	5.82	7.43	8.77
12	3.082	3.373	3.621	3.840	4.036	4.21	4.38	4.53	4.67	4.80	5.05	5.27	5.47	5.65	5.82	7.49	8.89
13	3.055	3.346	3.595	3.814	4.011	4.19	4.36	4.51	4.65	4.79	5.03	5.26	5.46	5.65	5.82	7.54	9.00
14	3.033	3.324	3.572	3.792	3.989	4.17	4.34	4.49	4.64	4.77	5.02	5.25	5.45	5.64	5.82	7.58	9.10
15	3.014	3.304	3.553	3.773	3.971	4.15	4.32	4.48	4.62	4.76	5.01	5.24	5.45	5.64	5.82	7.62	9.20
16	2.998	3.288	3.536	3.757	3.955	4.14	4.30	4.46	4.61	4.75	5.00	5.23	5.44	5.64	5.82	7.66	9.28
17	2.984	3.273	3.522	3.742	3.941	4.12	4.29	4.45	4.60	4.74	4.99	5.23	5.44	5.64	5.82	7.70	9.36
18	2.971	3.260	3.508	3.729	3.929	4.11	4.28	4.44	4.59	4.73	4.99	5.22	5.44	5.64	5.82	7.73	9.43
19	2.960	3.248	3.497	3.718	3.918	4.10	4.27	4.43	4.58	4.72	4.98	5.22	5.44	5.64	5.82	7.76	9.50
20	2.950	3.238	3.487	3.707	3.908	4.09	4.26	4.42	4.57	4.71	4.97	5.21	5.43	5.64	5.83	7.78	9.56
22	2.933	3.220	3.469	3.690	3.890	4.08	4.25	4.41	4.56	4.70	4.96	5.21	5.43	5.63	5.83	7.83	9.68
24	2.919	3.206	3.454	3.675	3.876	4.06	4.23	4.39	4.55	4.69	4.96	5.20	5.42	5.63	5.83	7.87	9.78
26	2.908	3.193	3.441	3.663	3.864	4.05	4.22	4.38	4.54	4.68	4.95	5.19	5.42	5.63	5.83	7.91	9.87
28	2.896	3.183	3.431	3.652	3.854	4.04	4.21	4.38	4.53	4.67	4.94	5.19	5.42	5.63	5.83	7.94	9.95
30	2.888	3.174	3.442	3.643	3.845	4.03	4.20	4.37	4.52	4.67	4.94	5.19	5.42	5.63	5.83	7.97	10.02
40	2.858	3.143	3.390	3.611	3.814	4.00	4.18	4.34	4.50	4.64	4.92	5.17	5.41	5.63	5.84	8.08	10.30
60	2.828	3.112	3.358	3.580	3.783	3.97	4.15	4.31	4.47	4.62	4.90	5.16	5.40	5.63	5.84	8.21	10.64
100	2.804	3.086	3.333	3.555	3.758	3.95	4.12	4.29	4.45	4.60	4.89	5.15	5.40	5.63	5.85	8.33	10.97
∞	2.772	3.051	3.297	3.518	3.722	3.91	4.09	4.26	4.42	4.57	5.86	5.13	5.39	5.63	5.86	8.54	11.66

For $n_2 = 1$ and $n_2 = 2$ use $R'_{p,2} = 12.706$ and $R'_{p,2} = 4.303$ respectively for all values of p.

7. That is, this test gives levels of 5% **per degree of freedom.**

TABLE 2.—Significant Ranges R'_{p,n_2} for a 1% Level Multiple Comparisons Test[8]

$n_2 \backslash p$	2	3	4	5	6	7	8	9	10	11	13	15	17	19	21	51	101
3	8.260	8.701	9.044	9.325	9.564	9.77	9.96	10.13	10.27	10.41	10.65	10.86	11.04	11.21	11.36	12.70	13.69
4	6.511	6.979	7.359	7.679	7.957	8.20	8.42	8.62	8.81	8.98	9.29	9.56	9.80	10.02	10.22	12.07	13.55
5	5.702	6.157	6.535	6.858	7.144	7.40	7.63	7.84	8.04	8.22	8.55	8.85	9.11	9.35	9.58	11.71	13.49
6	5.242	5.682	6.050	6.370	6.655	6.91	7.15	7.36	7.56	7.75	8.09	8.40	8.67	8.93	9.16	11.47	13.47
7	4.948	5.373	5.733	6.048	6.329	6.58	6.82	7.04	7.24	7.43	7.77	8.09	8.37	8.63	8.88	11.30	13.45
8	4.745	5.158	5.509	5.819	6.097	6.35	6.58	6.80	7.00	7.19	7.54	7.86	8.15	8.42	8.66	11.18	13.45
9	4.596	4.998	5.344	5.649	5.923	6.17	6.41	6.62	6.82	7.02	7.36	7.68	7.98	8.25	8.50	11.08	13.45
10	4.482	4.876	5.216	5.517	5.788	6.04	6.27	6.48	6.69	6.87	7.23	7.55	7.84	8.11	8.37	11.00	13.45
11	4.393	4.780	5.114	5.411	5.680	5.93	6.16	6.37	6.57	6.76	7.11	7.43	7.73	8.00	8.26	10.93	13.46
12	4.320	4.702	5.032	5.326	5.592	5.84	6.06	6.28	6.48	6.67	7.02	7.34	7.64	7.91	8.17	10.88	13.46
13	4.260	4.637	4.963	5.254	5.519	5.76	5.99	6.20	6.40	6.59	6.94	7.26	7.56	7.84	8.09	10.83	13.47
14	4.210	4.582	4.905	5.194	5.457	5.70	5.92	6.14	6.33	6.52	6.87	7.19	7.49	7.77	8.03	10.79	13.48
15	4.168	4.536	4.856	5.143	5.404	5.64	5.87	6.08	6.28	6.46	6.82	7.14	7.43	7.71	7.97	10.75	13.48
16	4.131	4.496	4.814	5.098	5.358	5.60	5.82	6.03	6.23	6.42	6.76	7.08	7.38	7.66	7.92	10.72	13.49
17	4.098	4.461	4.777	5.060	5.317	5.56	5.78	5.99	6.18	6.37	6.72	7.04	7.34	7.62	7.88	10.70	13.49
18	4.070	4.431	4.744	5.025	5.282	5.52	5.74	5.95	6.14	6.33	6.68	7.00	7.30	7.58	7.84	10.67	13.50
19	4.046	4.404	4.716	4.995	5.250	5.49	5.71	5.92	6.11	6.30	6.64	6.96	7.26	7.54	7.80	10.65	13.50
20	4.023	4.379	4.689	4.968	5.222	5.46	5.68	5.88	6.08	6.27	6.61	6.93	7.23	7.51	7.77	10.63	13.51
22	3.987	4.338	4.646	4.922	5.174	5.41	5.63	5.83	6.03	6.21	6.56	6.88	7.18	7.46	7.72	10.59	13.52
24	3.956	4.304	4.609	4.883	5.134	5.37	5.58	5.79	5.98	6.17	6.51	6.83	7.13	7.41	7.67	10.56	13.53
26	3.930	4.276	4.579	4.851	5.100	5.33	5.55	5.75	5.94	6.13	6.47	6.79	7.09	7.37	7.63	10.54	13.54
28	3.907	4.252	4.553	4.824	5.072	5.30	5.52	5.72	5.91	6.10	6.44	6.76	7.06	7.34	7.60	10.52	13.55
30	3.889	4.231	4.531	4.800	5.048	5.28	5.49	5.69	5.89	6.07	6.41	6.73	7.03	7.31	7.57	10.50	13.55
40	3.824	4.160	4.454	4.719	4.962	5.19	5.40	5.60	5.79	5.97	6.31	6.63	6.92	7.20	7.47	10.43	13.58
60	3.762	4.091	4.379	4.640	4.879	5.10	5.31	5.51	5.70	5.88	6.21	6.53	6.82	7.10	7.36	10.36	13.62
100	3.712	4.036	4.320	4.577	4.813	5.03	5.24	5.44	5.62	5.80	6.13	6.44	6.74	7.01	7.28	10.30	13.66
∞	3.643	3.958	4.235	4.486	4.716	4.93	5.13	5.32	5.51	5.68	6.01	6.32	6.61	6.88	7.14	10.20	13.75

For $n_2 = 1$ and $n_2 = 2$ use $R'_{p,1} = 33.657$ and $R'_{p,2} = 9.925$ respectively for all values of p.

8. That is, this test gives levels of 1% **per degree of freedom.**

be significant according to an F test before a difference is accepted as significant, the test meets the first part of the main requirement completely. By never failing to decide that a difference is significant unless such a decision would contravene the first part, it can also be seen to meet the second part of the requirement as well as possible.

A fairly short routine for applying the test may be developed in two stages.

Stage 1 is similar to Newman's multiple range testing procedure and is based on the following rule which gives a conservative first approximation to rule 1. *Rule 2*: The difference between any two means x_i and x_j is significant at the level α provided the range of each p-treatment enveloping combination of x_i and x_j exceeds a least significant range $R_{p,n_2,\alpha}$, where $R_{p,n_2,\alpha} = sR'_{p,n_2,\alpha}$, s is the standard error of a treatment mean, and $R'_{p,n_2,\alpha}$ is selected from table 1 or 2 depending on α and on n_2, the degrees of freedom for s. If any one of the ranges does not exceed the required value the decision is deferred to the next stage of the test.

The first step is to draw up a table of the least significant ranges for $p = 2, 3, \ldots, n$. Since n_2 and α will have the same values throughout a given test, these least significant ranges may be adequately denoted by $R_2, R_3, \ldots, R_n$. Space should be left in this table for a corresponding row of least significant sums of squares $S_p = \frac{1}{2}R^2_p$, some of which will be needed subsequently in the second stage.

Since the values $R_2, R_3, \ldots, R_n$ are always monotone increasing, at least for 5% and 1% level tests, the application of rule 2 requires the inspection of only one inequality for each of the larger differences and none at all for the remainder, provided each difference is inspected before the ones it envelopes. If a decision is deferred for any difference, the decisions for all the differences it envelopes must be deferred at the same time. The rule for each difference inspected in this way is simply: If $x_j - x_i > R_p$, $x_j - x_i$ is significant; where p is the number of means for which $x_j - x_i$ is the range, that is, $p = j - i + 1$. If $x_j - x_i \not> R_p$ defer decisions for all differences in the group $x_i, x_{i+1}, \ldots, x_j$. There is one exception to the latter part of this rule. In the case of a difference between two consecutive means, if $x_{i+1} - x_i \not> R_2$ the difference is not significant, and the decision need not be deferred.

The following example shows the application of stage 1 of a 5% level test to the foregoing pasture data.

Example 6: On multiplying the standard error of a mean, $s = .3396$, by the appropriate values in table 1 for $n_2 = 30$ the following values are obtained for $R_2, R_3, \ldots, R_{10}$:

p	2	3	4	5	6	7	8	9	10	11
R	.98	1.08	1.16	1.24	1.31	1.37	1.43	1.48	1.53	1.59
S	-	.583	.673	.769						

(The S values included in the table are not calculated till actually required in the second stage of the test, which is applied in example 7.)

On using these R values we find that all pairs of means not appearing together in a common bracket in the following table differ significantly from one another. Decisions about differences between all means bracketed together are deferred till stage 2 with the exception of K - F which is not significant.

F	K	D	E	A	J	B	G	C	H	I
2.85	3.60	3.94	4.05	4.55	4.96	5.03	5.41	5.96	6.09	6.97

In obtaining these results, a good system is to start by comparing I with F, then I with K, and so on to I with C where the inequality first breaks down with I - C = 1.01 $\not>$ 1.08. The bracket is then placed around CHI. Next compare H with F, H with K, ... H with J in turn terminating at H - J = 1.13 $\not>$ 1.24. The bracket is then placed around JBGCH. Continue in this way comparing C with the rest, G with the rest and so on, making sure never to test any difference already included within a bracket.

The above procedure never accepts a difference as significant unless it is significant by rule 1. This follows from the derivations of the tabled values which are given by the relationships[9]

$$\begin{aligned} R'_{p,n_2,\alpha} &= \sqrt{2(p-1)}F_{p-1,n_2,\alpha_p}, \quad n_2 > 2, \\ R'_{p,n_2,\alpha} &= \sqrt{2F}_{1,n_2,\alpha} = \sqrt{2}t_{n_2,\alpha}, \quad n_2 = 1, 2. \end{aligned} \tag{2}$$

The change in derivation for $n_2 = 1, 2$, is needed because $(p-1)F_{p-1,n_2,\alpha_p}$ is monotone increasing with respect to p for $n_2 > 2$, but monotone decreasing for $n_2 = 1, 2$, and the validity of the procedure requires that $R'_{p,n_2,\alpha}$ be defined as the largest of the values $\sqrt{2(i-1)}F_{i-1,n_2,\alpha_i}$, $i = 2, 3, \ldots, p$.

Stage 2 consists of a rigid application of rule 1 to the differences for which decisions have been deferred in stage 1. In the following description we will now let $x_1, x_2, \ldots, x_s$ represent a set of ranked means left bracketed together at the end of that stage. The procedure will follow the same pattern for all such groups.

9. Evaluated by using K. Pearson's Tables (1934a and 1934b).

The aim for a group is first to test the range $x_n - x_1$. The significances of the variances of all enveloping combinations of (x_1,x_n) except the following have already been established in stage 1.

$$\begin{array}{l}(x_1,x_n),\\ (x_1,x_2,x_n),\ (x_1,x_3,x_n),\ \ldots,\ (x_1,x_{n-1},x_n)\\ \ldots\\ (x_1,x_2,\ \ldots,\ x_n).\end{array} \tag{3}$$

The main requirement now is to show either that the variance of one of these combinations is not significant making $x_n - x_1$ not significant, or that the variances of all are significant making $x_n - x_1$ significant. The work involved in this will consist of the examination of rarely more than three or four inequalities.

In testing the variance of any one of the combinations (3) except the first, (x_1,x_n), we use the rule: if $SS > S_p$ the variance is significant and not otherwise, where SS is the sum of squares for the combination, p is the number of means it contains and S_p is the least significant sum of squares for p means obtained as previously stated from $S_p = \frac{1}{2}R^2_p$. As each value of S_p is calculated it is entered in the table already prepared for this purpose. In testing the variance of the first combination we use the rule: if $x_n - x_1 > R_2$ the variance is significant but not otherwise.

The first step is to test the sum of squares of the combination containing the whole group, that is $(x_1,x_2,\ \ldots,\ x_n)$. If this is significant we turn to the first combination. If $x_n - x_1 > R_2$, it may also exceed the least significant range for a combination of say 4 treatments. From this we would know immediately that the variances of all combinations with 4 treatments or less are significant, and would then proceed to an examination of 5-treatment combinations. In dealing with these we would pick the one with the smallest variance. Generally it will be possible to do this by inspection. Then if the sum of squares of this particular combination is significant so also would be the sums of squares for the remaining 5-treatment combinations. Furthermore, if this sum of squares also exceeds the significant value for a combination of say 7 treatments it would follow that the variances of all combinations with 7 treatments or less would be significant. We would then proceed to an examination of the 8-treatment combinations, and so on.

As a rule groups of this type will be relatively small and the process will give a decision fairly rapidly. If $x_n - x_1$ is not significant all differences between single means in the group $x_1,x_2,\ \ldots,\ x_n$ are not significant. If $x_n - x_1$ is significant the stage 1 procedure is then continued to the point to which it would have gone had $x_n - x_1$ been found significant in the first application of stage 1. This in turn produces one or two groups to which the stage 2 procedure is again applied, and so on.

The following example shows the applications of the second stage

of a 5% level test to the bracketed groups left at the end of stage 1 in example 6.

Example 7:

GROUP CHI: $SS_{CHI} = .6038 > S_3 = .583$, I - C $= 1.01 > R_2 = .98$, hence I - C is significant.

GROUP JBGCH: $SS_{JBGCH} = 1.0798 > S_5$, H - J $= 1.13 > R_3$, $SS_{JBGH} = .8037 > S_3$, hence H - J is significant.

GROUP AJBG: $SS_{AJBG} \not> S_4$ hence G - A is not significant.

GROUP DEAJB: $SS_{DEAJB} > S_5$, B - D $> R_3$, $SS_{DAJB} > S_4$, hence B - D is significant.

GROUP KDEA: $SS_{KDEA} \not> S_4$, hence A - K is not significant. Next, on continuing stage 1 beyond the stopping points removed in finding I - C, H - J, and B - D significant, we proceed to the following end-of-stage 1 result:

F K D E A J B G C H I

2.85 3.60 3.94 4.05 4.55 4.96 5.03 5.41 5.96 6.09 6.97

At this point we may conclude that I - H is not significant. On applying stage 2 steps to the new groups we have:

GROUP BGCH: $SS_{BGCH} > S_4$, H - B $> R_2$, $SS_{BGH} \not> S_3$, hence H - B is not significant.

For each of the groups JBCG, EAJB, and DEAJ, the sum of squares for all means is not significant hence each group contains no significant differences.

The complete results of the restricted form of the proposed test may now be stated by saying that the differences between all pairs of means not enclosed in a common bracket in the above diagram are significant. All other differences between single means are not significant.

The above test meets the *given objective* in the best way according to the main requirement. This objective, it is recalled, is to test only the differences between single means taken in all possible pairs. By making certain additions to this aim however, it is possible to improve the general power of the procedure a little without contravening the main requirement.

Sometimes the variance of a group of means is significant but the range is not. This occurs for instance in the group BGCH in example 7. In any such group having a significant variance we can argue that there is at least one comparison which may be accepted as significant. This may be put in the following way.

Let $x_1, x_2, \ldots, x_n$ represent the means in a group and consider the

comparison $c = k_1x_1 + k_2x_2 + \ldots + k_nx_n$, where $k_i = (x_i - \bar{x})$, $i = 1, \ldots, n$. The estimated variance of this comparison is $S^2_c = \Sigma k^2_i s^2 = \Sigma(x_i - \bar{x})^2 s^2$, and from this it follows, that if the sum of squares of the group is significant, that is, if $\Sigma(x_i - \bar{x})^2 > S_n$, then $c/s_c > R_n/\sqrt{2}\,s$. Thus c is as large relative to its standard deviation, s_c, as a significant difference between single means, $x_n - x_1$ would be relative to its standard deviation, $\sqrt{2}\,s$. Hence when the variance of a group is significant we may decide that the comparison c at least is significant. In other words we may accept the hypothesis H: $\Sigma k_i \mu_i > 0$ where k_i is the value of the observed deviate $(x_i - \bar{x})$, $i = 1, 2, \ldots, n$.

This type of decision may be put in less specific forms, which will be adequate for most purposes, by dividing the group at its mean and deciding that weighted averages of the subgroups differ significantly, or that at least one member of one subgroup is significantly different to at least one member of the other. Henceforth, for the sake of brevity, we will refer to a decision of this type as the decision that the two subgroups are significantly different.

Where a group is a subset of a larger group, decisions of this kind are subject to restrictions related to the enveloping combinations. The complete form of the proposed test is developed along these lines and may be given as the following generalization of the restricted test.

COMPLETE TEST.—Let U and V represent two subgroups containing u and v means each, such that all members of U and V are respectively less than and greater than the mean of the two subgroups combined.

The complete test consists of the application of the following rule to the differences between all pairs of subgroups U and V which can be selected subject to the restriction that no subgroup of U is significantly different to any subgroup of V by the same rule. *Rule* 3: The difference between U and V is significant at the level α if the variance of each p-treatment enveloping combination of U and V is significant according to an α-per-degree-of-freedom-level F test as previously defined in rule 1. (For the purpose of this rule we will say that any combination C, containing p means, $p \geqslant u + v$, such that the lowest u members of C are each not higher than the corresponding members of U and highest v members in C are each not lower than the corresponding members of V, is a p-treatment enveloping combination of U and V.) If anyone of these variances is not significant, the difference is not significant.

Because of the restriction on the selection of the subgroups U and V, the complete test may be divided into a three stage procedure in which the first two stages are identical with those already given for the restricted test and the third stage alone is new. The work of the third stage is limited entirely to each group of means in which there are no significant differences between single members but for which the total sum of squares is significant.

By requiring that the variance of each enveloping combination be significant before a difference is accepted as such, this complete test also meets the first part of the main requirement. By never failing to reject the homogeneity hypothesis for any combination unless such a decision would contravene the first part, it can also be seen to meet the second part of the requirement completely.

The third stage required to complete the restricted test in examples 6 and 7 is given in example 8.

Example 8: The only group in example 7 with a significant sum of squares but with no significant differences between single means is BGCH for which the results are as follows:

B	G	C	H
5.03	5.41	5.96	6.09

By inspection the subgroups B and CH alone appear to differ. They qualify for testing because no subgroup of C and H is significantly different to B. The only enveloping combination whose variance has not already been tested and found significant is the combination BCH. On testing this, we find $SS_{BCH} > S_s$ hence the groups B and CH are significantly different. This result together with those for example 6 and 7 finalize the results of the complete test for these data:

COMPROMISE FOR STAGE 3.—As a rule the number of comparisons requiring attention in the third stage will be small and the work will terminate quickly. Sometimes however, the numbers will be large and the application of the full third stage may be unnecessarily tedious. In such cases a compromise is proposed which keeps the work down and sacrifices very little. This consists of limiting the application of rule 3 to what appears to be the most important between-subgroup difference in the given group, without bothering to observe the restriction that parts of the chosen subgroups should not be significantly different.

The value of having a test defined *a priori* for such an extensive set of comparisons lies not so much in actually applying it to all such comparisons in any one case, as in the wide choice it allows for selecting interesting comparisons *a posteriori*, still giving a valid test for each. The relaxation of the selection restriction only means that two subgroups may be accepted as significantly different when more detail may have been obtained enumerating which parts of these subgroups are significantly different and which are not. This is unimportant if the subgroups concerned are reasonably compact.

The complete test using the compromise for stage 3 is illustrated in example 9.

Example 9: Snedecor (1946) gives, as example 11.28, the results of a 7x7 Latin square fertilizer trial with potatoes. The estimated standard error of a treatment mean is $s = 9.52$ and this is also based on $n_2 = 30$ degrees of freedom. The least significant ranges and sums of squares for a 5% level test are:

p	2	3	4	5	6	7
R	27.5	30.2	32.6	34.7	36.6	38.4
S	--	456	531	602	670	

From the least significant ranges, the results of stage 1 of the test are found to be,

A	D	C	B	E	F	G
341.9	360.4	360.5	363.1	379.9	386.3	387.1

where the brackets have the same connotation as before. The work for stage 2 is now:

GROUP DCBEFG: $SS_{DCBEFG} > S_6$, G - D $\not>$ R_2, hence G - D is not significant.

GROUP ADCB: $SS_{ADCB} \not> S_4$, hence this group contains no significant differences.

Thus the results at this stage are still that G - A, F - A, and E - A alone are significant.

Of the two groups remaining, only DCBEFG qualifies for testing in stage 3 because its sum of squares alone has been found significant. Since DC and FG constitute two well separated compact subgroups, we shall test the difference between these. For these the enveloping combinations whose variances have not already been shown to be significant are DCFG, DCBFG, and DCEFG. Using a skipping system like that of stage 2 we get $SS_{DCFG} > S_6$ which immediately establishes the significances of all three variances, hence the difference between DC and FG is significant. Thus the final results are that G - A, F - A, E - A and DC versus FG are significant.

A SPECIAL APPLICATION IN VARIETAL TRIALS

Suppose that several crop varieties have been grown and ranked in order of merit according to their average yields. It may be desired to choose a certain number of these so as to be reasonably sure of including the best. This problem could be met by taking the variety with the highest yield and all those that did not differ significantly from it according to an α-level multiple comparisons test. Only a partial application of the restricted form of the test would be required for this purpose.

In a more general case it may be desired to choose a number so as to include the best r varieties. This could be met in a similar way by taking all varieties which are not significantly less than the r^{th} variety according to the same procedure.

CONCLUDING REMARKS

From the examples it will be seen that with a little practice and with modern calculating machines the proposed test is not unduly difficult to apply and provides results which are both useful and intuitively acceptable.

The statistical merits of the test rest completely on the acceptability of the main requirement developed in section 4 and the a-per-degree-of-freedom levels given in section 5.

The acceptability of the main requirement is fairly well confirmed in detail by an average weighted risk analysis given in the companion paper (1952). The use of the a-per-degree-of-freedom levels represents a radical step relative to other comparable procedures in the literature. After very lengthy consideration and discussion however, these levels do appear to be more appropriate than the more orthodox uniform levels $a_p = a$ and effect considerable increases in the general power of the procedure.

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Bottom Fauna and Temperature Conditions in Relation to Trout Management in St. Mary's River, Augusta County, Virginia[1]

EUGENE W. SURBER[2]

Biologist, Federal Security Agency, Public Health Service, Chicago, Ill.

St. Mary's River is one of the better trout streams in the George Washington National Forest and, as a consequence, has been the subject of several investigations (Surber, 1940). It arises from small springs, and flows through a narrow, very rocky, uninhabited mountain ravine (Figure 1) in eastern Augusta County, Virginia as a tributary of South River of the James River watershed. The stream flows over a rubble, boulder- strewn, and gravel bed of quartzite, apparently dissolving little of the elements conducive to high biological production. It has very soft water and is slightly acid. As shown in Table I, the average methyl orange alkalinity is about 4.69 parts per million, the pH is 6.8, and the free carbon dioxide content is 3.1 parts per million.

According to Mr. R. Lybrook, once chemist for one of the manganese mining companies operating in the valley, the manganese content of St. Mary's River water was relatively high, averaging about 0.316 parts per million. The manganese ore mined in the valley was water deposited and occurred in its purest form as stalactites and stalagmites.

The average width, as reported by McGavock and Davis (1935) on May 17, 1934, was 9 feet upstream from the National Forest boundary to Mine Bank (on map, just above Mine Bank Creek). From this point to its source, the stream averaged 7 feet in width. On that date, the flow was estimated at 7.9 cubic feet per second, with a gradient of 150 feet per mile, in the lower section and 4.3 cubic feet per second and a gradient of 175 feet per mile in the upper section. The survey party making the original survey gave the stream a pool grade of "B" indicating average conditions with many pools of suitable depth and adequate shelter. Suitable depth might be defined as depths of 2 feet or more and adequate shelter may be provided by overhanging banks, by the presence of flat rocks or boulders underneath which trout may hide.

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2 Formerly Biologist, Fish and Wildlife Service, Kearneysville, West Virginia; Adjunct Professor of Biology, Virginia Polytechnic Institute, Blacksburg, Virginia.

FIGURE 1. General location of St. Mary's River, George Washington National Forest, Virginia.

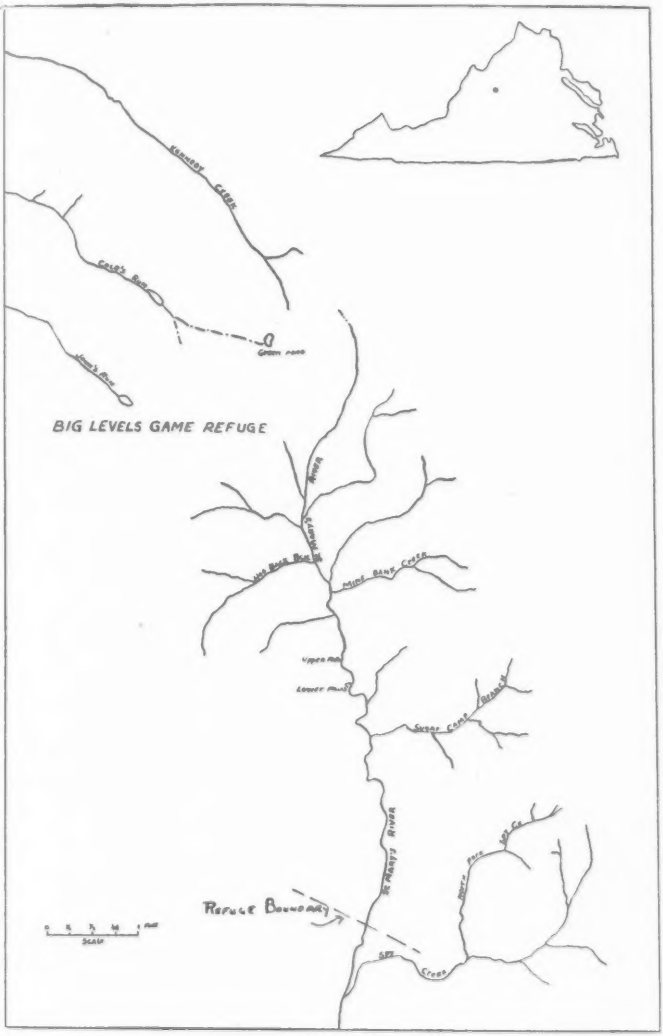


TABLE I.—Chemical Data, St. Mary's River, Virginia.

Date	Water Temperature degrees F.	Hydrogen-ion concentration	Free carbon dioxide p.p.m.	Dissolved oxygen p.p.m.	Methyl orange alkalinity p.p.m
Aug. 29, 1938	63.0	6.9	5.0	8.6	8.75
Sept. 22, 1938	52.5	6.9	3.3	9.4	5.00
Nov. 9, 1938		6.7	2.0	11.1	2.50
Apr. 4, 1939	49.5	6.8	1.5	10.6	2.50
Average	55.0	6.8	3.1	9.9	4.69

or simply by surging water at the head of a pool where depths are usually greatest.

During World War I, a railroad spur was constructed in the St. Mary's Valley to the Red Mountain Mine where manganiferous iron ore was obtained. Mines were also located on Mine Bank Mountain. Residents in the section have stated that during the operation of these mines, the stream was almost continuously roily due to the washing of ore and was unfit for trout. After World War I, the mines and railroad were abandoned; rails were removed and by 1935 the stream was clear and contained a few nice trout. The railroad grade had grown up in briers and brush, and there was no one residing within the game management area. Fly-fishing is difficult due to the canopy of alders which arch over the stream bed and shade it throughout. There are impassable falls at two points about half-way up the stream (see Figure 1). While the stream always has a good flow within the Big Levels Game Management Area, the lower boundary of which is about one mile above the mouth of Spy Creek, the stream bed has been seen entirely dry at the mouth of Spy Creek. On the whole, the stream maintains a better flow than the majority of streams in the George Washington National Forest area, and it has above average natural protection in the form of deep pools and sheltering boulders.

TEMPERATURE CONDITIONS

A continuous record of the temperature of St. Mary's River was obtained with a recording thermometer for the period October 18, 1936, to October 18, 1937, at a point about 0.75 mile below the game management area boundary. Figure 2 depicts temperature conditions in the stream graphically.

A maximum temperature of 68° F., and mean monthly temperatures

of 62.75 in June, 63.20 in July, 64.93 in August, and 58.42 in September, were recorded. Daily variations in water temperature, even on the warmest days, were very small due principally to the narrowness of the mountain ravine through which the stream flows and a canopy of alder bushes over the stream. The maximum temperature on the warmest days occurred between 3:00 and 5:00 p.m., while the minimum occurred between 3:00 and 6:00 a.m. There is reason to assume that the effective feeding temperature range for trout lies between 47° and 68°F., which seems probable in the St. Mary's River. If this feeding temperature range is accepted, there were 231 effective feeding days, or parts of days (see Table II) during the period October 18, 1936 to October 18, 1937. The temperature data collected during the early spring of 1937 show only seven days prior to April 15, then the opening day of the trout season, when trout could have fed sufficiently to grow and improve their condition.

The optimum temperature for feeding and growth of brook and rainbow trout is 55-60°F., according to Davis (1929) and Embody (1936). Optimum conditions, therefore, prevail in the St. Mary's River through the greater part of May, June, July, August, and September. According to Embody (1936), brook, brown, and rainbow trout do not cease feeding altogether even at the extreme temperatures of 75 and 77°F., but only a very minor portion of the food offered is consumed and growth is practically nil. It seems doubtful that such extremes of temperature have ever been attained in the St. Mary's River, and

TABLE II.—Number of days in which temperatures of 47° to 65°F. were recorded, St. Mary's River, Virginia.

Month	Year	Number of days
October	1936	14
November	1936	14
December	1936	0
January	1937	8
February	1937	0
March	1937	3
April	1937	21
May	1937	31
June	1937	30
July	1937	31
August	1937	31
September	1937	30
October	1937	18
Total		231

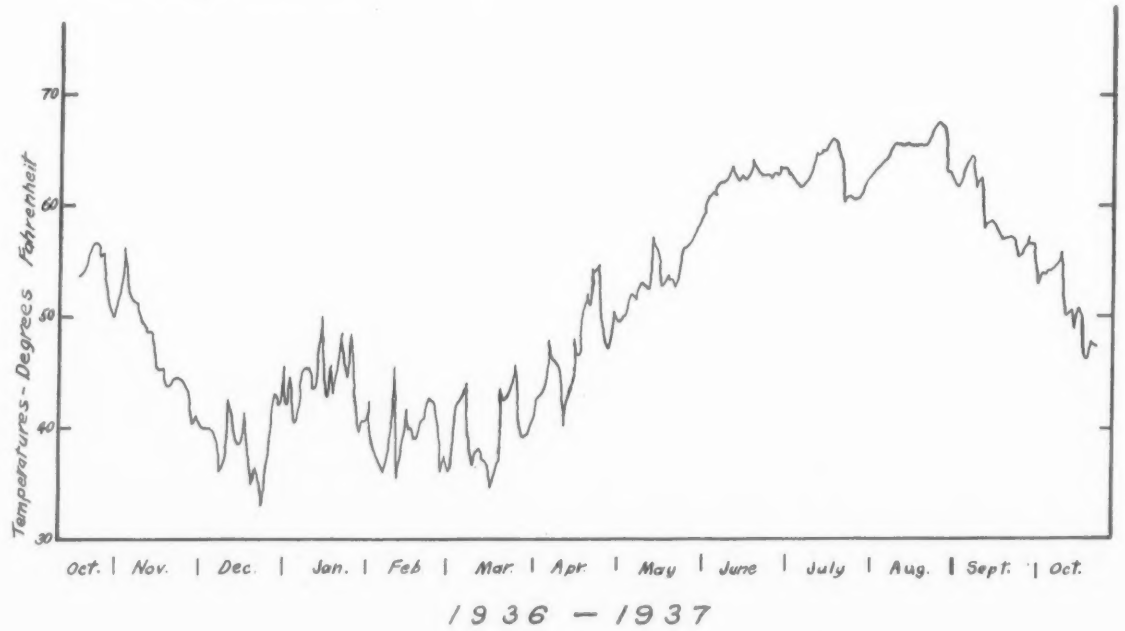
from our own observations it appears that temperature conditions are nearly ideal for growth during at least five months of the year. Needham (1938) notes that brook trout thrive best in streams that show mid-summer maximum temperatures around 66°F. Gerrish (1935) observed that the growth rate of trout depends upon the length of the growing season and the inclination to feed within that period. "Water temperature," he states, "is only material in so far as it affects the amount of dissolved oxygen in the water" (*ibid,* p. 14). He believes that trout cannot feed below 40°F., also that even between 40° and 56°F., a too sudden rise of temperature or a sharp fall of atmospheric pressure will put trout off feeding for a while. In the Lambourn, he found trout feeding freely between 40° and 56°F., while from 57° upward the ability to feed decreased rapidly until at 60°F. it ceased. He observed that yearlings were less sensitive to temperature changes than were older fish, and fry were less sensitive than yearlings. In the same paper, he pointed out that trout in such larger rivers as the Kennet fed up to 66°F., and in New Zealand he observed that they fed heavily up to 73°F. and probably higher. In these larger streams he believed that a higher iodine content enabled them to feed at relatively high temperatures.

In connection with the maximum temperatures at which trout feed, it was interesting to note that on July 13, 14, 1937, Dr. James S. Gutsell, Reuben O. Knuth and the writer collected from St. Mary's River 82 brooks and 56 rainbows for growth measurements using artificial flies and spinners. On both of these days, the maximum water temperature was 66°F., while the average daily temperatures were 65.56 and 65.75, respectively. On these days, the trout were obviously feeding vigorously.

The temperature data collected during the early spring of 1937 show there were only seven days prior to April 15 when trout could have fed sufficiently to grow and improve their condition. This information might be offered as an argument against the opening of a trout season, even in this southerly section, much before May 1.

Beginning August 27, 1935, square foot bottom samples, usually 18 to 20, were taken at monthly intervals, except for two or three months in late winter, until August 24, 1937. The samples were collected with a squarefoot bottom sampler using the equipment and technic described by Surber (1936). The results are summarized in Table III. An analysis of the data shows an average wet weight production in grams per square foot of 1.04 grams (dry, 0.22 gram) for the four months during which collections were made in 1935 (August, September, October, and late November). During the nine months, mid-April to mid-December of 1936, the average wet weight of bottom animals was 1.12 grams per square foot (dry 0.28 gram). In 1937, collections were continued from April 1 to August 24. The dry weight of the 1937 bottom samples was not determined, but the wet weight averaged 1.06 grams per square

FIGURE 2. Temperature data, St. Mary's River, Virginia, showing average daily variations from October 1936 through October, 1937.



foot. Again in 1938, a series of 10 samples per month was collected from March 23 to November 9. These samples averaged 1.37 grams per square foot. This average was slightly above that of the three previous years when larger numbers of samples were collected, but it serves to give additional evidence that the riffle areas average slightly more than 1.00 gram, wet weight, of potential food organisms per square foot per year.

This quantity of potential fish food organisms is believed to be about average for good mountain streams in this area.

The bottom fauna of Kennedy Creek, a smaller stream nearby in the Big Levels Refuge, and Spy Creek, a tributary of St. Mary's River, were studied during the same period in 1935, 1936, and 1937. Kennedy Creek had an average wet weight of 1.75 grams during this period while Spy Creek, also a small stream, averaged 1.80 grams per square foot during 1935-1926 as compared to the average of 1.07 grams per square foot in the St. Mary's River during the same period.

The data in Table II indicate that bottom animals are least abundant during late spring and early summer at the time when insect emergence is at its height. Bottom animals are most abundant during August, September, and October. Thus, plantings of fingerling trout, if made during the latter three months, are likely to find stream conditions at their best with respect to bottom foods.

Severe floods often occur during the spring period as they did on March 13, 1926 and again on April 26, 1937, when record or near record floods occurred. Their effect on abundance of stream animals is highly destructive, but considerable recovery usually is noted within one to three months' time.

Caddis larvae belonging to the Hydropsychidae, *Cheumatopsyche* and *Hydropsyche*, with brown or bright green bodies, were always present in considerable numbers in all bottom samples. The small caddis larvae of *Dolophilodes distinctus* Walker, with white bodies and bright yellow heads, were usually present. The larger *Rhyacophila fuscula* Walker, and *Rhyacophila torva* Hagen were quite common but did not occur in all samples. In sampling St. Mary's River during a DDT project during 1947, Hoffmann and Merkel (1948) found the genus *Cheumatopsyche* to predominate over *Hydropsyche* in their samples. They list *Hydropsyche* (near *slossonae* Banks) and the small pink-bodied Psychomyiidae.

The small turtle-shell-like cases of coarse sand grains containing the larvae of the caddis fly *Goera calcarata* Banks often occur over the rocks and boulders in abundance as does *Brachycentrus* and other caddis larvae. These are not readily removed from stones and are undoubtedly more abundant than the samples indicate.

The mayflies play an important part in the ecology of all of these

TABLE III.—Bottom fauna of the St. Mary's River (riffles only). Average numb

	Aug. 27, 1935	Sept. 26, 1935	Oct. 28, 1935	Nov. 26, 1935	Jan. 7, 1936
Number of samples	20	20	20	13	18
Total number of animals	2,044	2,212	2,224	1,310	1,545
Average number per sample	102.20	110.70	110.20	100.80	86.00
Average wet weight per sample	1.00	1.15	1.14	0.86	0.82
Average dry weight per sample	0.21	0.25	0.24	0.17	0.16
Oligochaeta (tube worms)	0.80	2.15	1.85	1.69	0.67
Crustacea (crayfish):					
Cambarus	1.05	-	0.03	0.23	0.17
Trichoptera (caddis fly larvae)					
Cheumatopsyche & Hydropsyche	42.60	50.00	38.10	29.31	18.28
Dolophilodes	1.05	6.40	14.70	1.23	0.33
Rhyacophila fuscula	0.05	0.35	0.90	0.15	0.50
Rhyacophila torva	0.20	0.40	1.75	1.23	0.44
Brachycentrus	-	-	1.45	2.31	1.61
Miscellaneous	5.75	1.60	0.15	0.53	1.69
Plecoptera (stonefly nymphs)					
Leuctra, Alloperla, etc.	12.80	2.10	1.50	2.23	1.78
Peltoperla	0.90	5.30	1.80	3.15	1.06
Perla and Acroneuria	1.95	3.30	2.35	3.69	2.39
Pteronarcys	0.10	0.30	0.20	-	0.06
Nemoura	-	-	-	-	-
Miscellaneous	0.05	0.10	2.75	2.20	3.17
Odonata (dragonfly iymphs)					
Aeschna	-	-	-	-	-
Lanthus	0.05	-	-	-	-
Miscellaneous	0.30	0.20	0.35	0.08	-
Ephemerida (mayfly nymphs)					
Stenonema	11.65	16.75	13.30	20.92	10.44
Baetis and Pseudocloeon	6.55	8.60	1.00	0.31	1.50
Paraleptophlebia	0.55	0.50	17.20	7.62	9.17
Iron	2.85	2.35	3.30	10.08	20.28
Ephemerella	0.65	0.55	3.20	5.92	4.78
Isonychia	1.40	-	1.05	0.08	-
Miscellaneous	-	2.35	0.30	-	-
Neuroptera (fish-flies)					
Nigronia	1.15	0.20	0.30	0.31	1.67
Miscellaneous	0.05	-	-	-	-
Coleoptera (beetles)					
Parnid adults	0.80	0.15	0.05	-	0.06
Parnid larvae	0.40	0.15	0.55	0.23	-
Psephenus	0.30	0.05	-	-	-
Miscellaneous	0.05	-	0.05	0.08	0.11
ptera (fly larvae)					
Atherix	1.30	0.75	0.45	0.23	1.22
Chironomidae	5.55	5.80	1.50	5.23	3.06
Eriocera	0.80	0.65	0.90	0.31	0.56
Simulium	0.15	0.45	0.25	-	0.17
Antocha	0.80	0.50	0.65	0.15	-
Miscellaneous	0.05	-	0.20	0.15	0.06
Vertebrates:					
Salamanders	0.45	0.20	0.20	0.54	0.39
Miscellaneous organisms:	0.10	0.25	-	-	-

es only). Average number of organisms per square foot.

Oct. 28, 1935	Nov. 26, 1935	Jan. 7, 1936	April 18, 1936	May 15, 1936	June 17, 1936	July 14, 1936	
20	13	18	16	15	20	18	
2,224	1,310	1,545	1,049	481	1,120	924	1
110.20	100.80	86.00	66.00	32.10	56.00	51.33	6
1.14	0.86	0.82	1.08	0.42	1.65	1.18	
0.24	0.17	0.16	0.23	0.10	0.41	0.42	
1.85	1.69	0.67	0.27	0.30	0.50	0.50	
0.03	0.23	0.17	0.31	0.53	0.70	0.56	
38.10	29.31	18.28	13.94	8.13	6.85	26.17	2
14.70	1.23	0.33	0.94	0.47	5.60	2.50	
0.90	0.15	0.50	0.31	-	0.85	0.44	
1.75	1.23	0.44	1.19	0.27	0.40	0.39	
1.45	2.31	1.61	-	0.07	0.05	-	
0.15	0.53	1.69	0.31	0.82	1.85	1.66	
1.50	2.23	1.78	2.25	1.13	1.45	1.33	
1.80	3.15	1.06	2.56	0.53	0.70	-	
2.35	3.69	2.39	2.69	0.53	2.15	2.33	
0.20	-	0.06	-	-	0.45	0.17	
-	-	-	2.31	0.20	0.55	-	
2.75	2.20	3.17	0.19	0.33	0.10	-	
-	-	-	0.06	0.07	-	0.44	
-	-	-	-	-	0.05	0.11	
0.35	0.08	-	0.06	0.07	0.05	-	
13.30	20.92	10.44	4.75	3.53	2.85	2.17	
1.00	0.31	1.50	0.75	1.47	3.00	3.00	
17.20	7.62	9.17	1 31	2.00	1.95	0.78	
3.30	10.08	20.28	15.69	2.87	7.50	1.39	
3.20	5.92	4.78	10.00	2.87	6.95	0.50	
1.05	0.08	-	-	0.20	0.10	-	
0.30	-	-	-	1.53	-	-	
0.30	0.31	1.67	0.25	0.13	0.53	0.17	
-	-	-	-	-	-	-	
0.05	-	0.06	-	-	0.10	0.06	
0.55	0.23	-	0.13	-	0.05	-	
-	-	-	-	0.13	0.05	-	
0.05	0.08	0.11	-	-	-	-	
0.45	0.23	1.22	0.25	0.13	0.50	0.94	
1.50	5.23	3.06	0.69	3.27	5.75	3.28	
0.90	0.31	0.56	0.63	0.40	0.50	0.22	
0.25	-	0.17	2.94	0.13	1.45	1.89	
0.65	0.15	-	0.19	-	0.25	0.06	
0.20	0.15	0.06	0.13	-	0.35	0.17	
0.20	0.54	0.39	0.25	0.20	0.20	0.06	
-	-	-	0.13	-	0.05	0.06	

uare foot.

July 14, 1936	Aug. 14, 1936	Sept. 16, 1936	Oct. 16, 1936	Nov. 17, 1936	Dec. 17, 1936	April 1, 1937	May 8, 1937	June 3, 1937	July 13, 1937	Aug. 24, 1937
18	20	19	19	19	16	18	19	20	20	20
924	1,351	2.470	1,986	1.810	886	1,440	763	680	2,362	2,887
51.33	67.55	130.00	104.50	95.30	55.40	80.00	44.88	34.00	118.10	144.35
1.18	1.96	1.28	1.26	0.65	1.05	1.06	0.68	0.58	1.42	1.58
0.42	0.48	3.20	0.30	0.15	0.23	-	-	-	-	-
0.50	0.05	0.16	0.75	0.11	0.38	1.10	0.30	0.10	0.65	0.95
0.56	1.20	0.52	0.37	0.16	0.19	0.17	0.20	0.45	0.55	0.55
26.17	29.00	50.05	28.11	17.79	9.25	8.50	2.70	2.45	2.34	30.65
2.50	1.30	4.00	1.99	4.26	1.06	0.50	0.20	0.70	6.90	5.70
0.44	0.35	-	0.11	0 95	0.13	0.40	0.16	0.45	0.05	-
0.39	0.20	0.47	1.95	0.89	0.75	0.75	0.40	0.20	0.40	0.05
-	-	-	0.11	1.21	1.75	0.60	0.20	0.20	-	0.35
1.66	2.90	1.00	0.32	0.32	0.50	0.80	0.70	0.30	1.40	2.60
1.33	1.20	2.53	14.28	8.58	5.94	3.90	3.90	1.15	21.40	14.35
-	0.10	5.26	2.58	0.84	0.38	0.80	0.36	0.10	7.85	4.60
2.33	2.75	4.05	4.53	3 37	1.25	3.20	1.60	1.60	4.35	6.95
0.17	0.60	0.42	0.16	0.16	0.31	0.10	-	0.15	0.20	0.15
-	-	-	-	0.05	-	0.20	0.26	0.05	-	-
-	0.25	-	5.53	0.63	3.31	0.10	0.31	-	0.80	-
0.44	0.60	0.21	0.11	-	0.13	-	0.05	-	0.15	-
0.11	0.10	0.05	0.05	-	-	-	-	-	-	-
-	-	-	-	0.05	0.13	-	0.05	-	0.05	0.20
2.17	6.05	33.68	20 53	19 94	10.44	8.20	3.40	1.50	3.30	11.75
3.00	2.65	5.26	1.79	0.58	-	2.10	1.40	2.85	17.30	8.25
0.78	0.35	3.15	17.84	19.47	9 50	6.70	4.60	5.15	4.65	4.55
1.39	5.20	2.37	0.58	10.89	2.06	17.40	5.70	3.10	3.00	0.85
0.50	2.05	0.52	0.05	3.32	1.81	6.30	2.80	1.60	1.60	1.60
-	0.25	0.47	0.16	0.21	0.13	0.10	-	-	-	0.45
-	0.10	-	-	-	-	1.10	-	0.20	0.05	0.05
0.17	1.10	1.11	0.68	0.42	1.56	0.10	0.60	0.60	1.90	2.75
-	-	-	-	-	0.13	-	-	-	-	-
0.06	-	0.84	0.11	0.05	-	0.05	-	-	0.20	0.45
-	0.10	0.11	0.42	0.21	-	0.30	-	0.15	0.20	0.10
-	-	0.05	0.16	-	-	-	0.10	0.10	0.05	0.05
-	-	-	-	-	-	-	0.05	-	0.05	-
0.94	7.30	10.74	3.26	4.47	2.31	1.10	0.70	1.25	1.20	3.30
3.28	0 50	0.89	0.68	0.52	0.75	2.80	4.80	3.30	12.00	40.25
0.22	0.65	0.95	1.52	1.52	0.38	1.10	0.60	0.70	1.10	0.90
1.89	0.01	0.52	0.05	0.26	0.31	10.40	-	1.05	2.50	0.35
0.06	0.10	0.05	0.68	0.63	0 06	0.90	0.50	0.15	0.20	0.20
0.17	0.15	-	-	0.11	0.06	0.40	0.16	0.15	0.05	0.40
0.06	0.20	0.05	0.37	0.37	0.38	-	0.10	0.10	0.10	0.20
0.06	0.20	0.11	0.16	-	0.06	-	0.20	0.10	0.20	0.80

mountain streams. The forms with much flattened heads and bodies, often large in size, move swiftly as one lifts stones from the water. The reddish-legged nymphs of *Stenonema fuscum* Clemens are abundant and *Stenonema varium* Traver, and *Stenonema pulchellum* Walsh are common. *Stenonema heterotarsale* McDunnough occurs in small and unimportant numbers. The mayfly nymphs of *Paraleptophlebia guttata* McDunnough and *Paraleptophlebia mollis* Eaton are nearly always present in bottom samples from St. Mary's River, regardless of stream velocities.

Among the common species of mayflies in the stream are *Ephemerella subvaria* McDunnough and the swift-moving *Isonychia sadleri* Traver. Species of *Baetis* and *Pseudocloeon* also have been recorded. Hoffman and Merkel (1948) recorded *Baetis cingulatus* McDunnough and *Pseudocloeon carolina* Banks in relatively small numbers.

A few stonefly nymphs are always present in St. Mary's River samples. Among the most conspicuous, largest and most active of these are the carnivorous *Acroneuria abnormis* Newman and *Acroneuria lycorias* Newman. The large *Pteronarcys proteus* nymphs are found in riffle samples containing decaying leaves. These samples also contain many of the small reddish brown roach-like stonefly nymphs of *Peltoperla arcuata* Needham which feed on plant debris. Among the smaller, swift running, not so numerous but conspicuous stonefly nymphs are the brilliant *Neophasganophora capitata* Pictet and *Isoperla bilineata* Say. Of lesser importance among the larger nymphs are such species as *Acroneuria depressa* Needham and Claasen and *Perla hastata* Banks. The stonefly nymphs of *Isoperla similis* Hagen are relatively uncommon.

Small stonefly nymphs of *Leuctra, Alloperla, Capnia,* etc., were common in the bottom samples, but rearing will probably be required before they can be identified to species.

The larvae of the fish-fly *Nigronia serricornis* Say, although unimportant numerically when compared with the abundance of the organisms listed above, are found in the majority of samples, and their relatively large bulk makes them one of the most important animals. The crayfish *Cambarus b. bartoni* (Fabricius) are less numerous than *Nigronia* but are still larger in size and are very important trout food organisms.

In 1938, surface current velocities were determined at the various points where bottom samples were ordinarily taken to determine, if possible, the effect which various current velocities had on the abundance and distribution of the bottom organisms. In making these surface current velocity measurements, a round cork of the type generally used by bass fishermen in this region was timed by a stop watch as it passed over a known distance. A variable distance was employed through which to float the cork, since it was impossible to use a standard distance,

particularly in fast water.

Table IV shows the results of these surface velocity determinations for 57 samples which are compiled with respect to average wet weights of bottom animals for each of the six surface velocity groups.

In the tabulations showing abundance of various genera at different velocities, Chironomidae larvae were omitted, although they were very likely present upon the stones in each sample. The mode of existence of the tendipedid species, usually in silk tubes on the surfaces of stones, makes accurate determinations of their abundance impossible because they dwell in the crevices and depressions from which they are not easily dislodged. They are, none the less, among the most important bottom fauna of the stream and very likely are important food organisms for small fish. Their wet weight per square foot in riffle samples is usually insconsequential.

TABLE IV.—Frequencies of occurrence of certain surface velocities and average number and wet weight of bottom animals in 60 bottom samples collected during 1938, St. Mary's River, Virginia.

Velocity in feet per second	Number of bottom samples	Average number of bottom animals per square foot	Average wet weight grams per square foot
0.50 - 0.99	2	99.00	3.33
1.00 - 1.49	14	147.86	1.31
1.50 - 1.99	19	115.47	1.01
2.00 - 2.49	14	152.21	1.23
2.50 - 2.99	7	124.71	1.55
3.00 - 3.49	4	339.25	3.16

These data indicate that most of the samples were collected at surface velocities of 1.00-2.5 feet per second and that the largest number of samples was taken at 1.5 - 1.99 feet per second. The collections were not sufficient to indicate definitely the effects of different velocities on the abundance of bottom animals at the various velocities. In the 0.50 - 0.99 group, only two samples were obtained. One of these contained a large crayfish which brought the average wet weight much above the average wet weight of succeeding groups which had larger numbers of samples. Between velocities of 1.00 - 2.50 feet per second, the average weight and abundance of bottom organisms remain about the same. In the four samples with velocities of 3.00 - 3.49 feet per second, both the numbers and weight of organisms increase decidedly. In these samples, the net spinning caddis larvae of the family Hydropsychidae alone, averaged 198 per square foot.

Table V lists the principal genera of bottom animals in St. Mary's River for different surface velocities of the stream. These data show,

TABLE V.—Abundance of several genera of aquatic organisms at different velocities, St. Mary's River, Virginia, 1938.

Number of samples	Velocity Feet per second	Crayfish	Fish-fly larvae	Mayfly nymphs				
		Cambarus	Nigronia	Iron	Baetis	Ephemerella	Paraleptophlebia	Stenonema
2	0.50-0.99							
Total number		2	0	1	7	2	18	11
Average number per sample		1	0	0.50	0.35	1.00	9.00	5.50
Frequency		1	0	1	1	1	2	2
Percent		50.00	0	100.00	50.00	50.00	100.00	100.00
14	1.00-1.49							
Total number		9	37	10	97	18	305	157
Average number per sample		0.64	2.64	0.71	6.93	1.29	21.79	11.21
Frequency		6	12	3	11	7	14	13
Percent		42.86	85.72	21.43	78.57	50.00	100.00	86.67
19	1.50-1.99							
Total number		7	20	22	82	62	334	193
Average number per sample		0.37	1.05	1.16	4.32	3.26	17.58	10.16
Frequency		4	10	8	12	12	19	18
Percent		21.05	52.63	42.11	63.16	63.16	100.00	94.74
14	2.00-2.49							
Total number		6	32	39	108	69	326	90
Average number per sample		0.43	2.29	2.79	7.71	4.93	46.57	6.43
Frequency		6	12	6	13	10	14	14
Percent		42.86	85.72	42.86	21.43	71.43	100.00	100.00
7	2.50-2.99							
Total number		2	18	8	30	9	93	14
Average number per sample		0.29	2.57	1.14	4.29	1.29	13.29	2.00
Frequency		1	6	3	6	4	7	4
Percent		14.29	85.71	42.86	85.71	57.14	100.00	57.14
4	3.00-3.49							
Total number		1	4	30	33	7	96	47
Average number per sample		0.25	1.00	7.50	8.25	1.75	24.00	11.75
Frequency		1	1	4	2	3	4	4
Percent		25.00	25.00	100.00	50.00	75.00	100.00	100.00

TABLE V. (continued)

Number of samples	Stonefly nymphs			Caddis fly larvae				Fly larvae	
	Perla and Acronueria	Leuctra	Alloperla	Cheumatopsyche and Hydropsyche	Rhyacophila	Dolophilodes	Hexatoma	Atherix	Antocha
2									
Total number	2	8	49	27	0	7	4	2	2
Average number per sample	1.00	4.00	24.50	13.50	0	3.50	2.00	1.00	1.00
Frequency	1	1	2	2	0	2	2	1	1
Percent	50.00	50.00	100.00	100.00	0	100.00	100.00	50.00	50.00
14									
Total number	34	55	147	843	5	24	13	10	24
Average number per sample	2.43	3.93	10.50	60.21	0.36	1.71	0.93	.71	1.71
Frequency	7	11	10	12	3	10	6	5	10
Percent	50.00	78.57	71.43	85.72	21.43	71.43	42.86	35.71	71.43
19									
Total number	39	20	126	754	8	64	39	13	60
Average number per sample	2.05	1.05	6.63	39.68	0.42	3.37	2.05	0.68	3.16
Frequency	15	8	16	19	6	14	11	9	14
Percent	78.95	42.11	84.21	100.00	31.58	73.69	57.89	47.37	73.69
14									
Total number	74	52	131	756	6	60	24	26	55
Average number per sample	5.29	3.71	9.36	54.00	0.43	4.23	1.71	1.86	3.93
Frequency	12	11	10	13	3	12	10	7	10
Percent	85.72	78.57	71.43	86.67	21.43	85.72	71.43	50.00	71.43
7									
Total number	14	45	27	339	0	76	10	7	23
Average number per sample	2.00	6.43	3.86	48.43	0	10.86	1.43	1.00	3.29
Frequency	4	4	5	7	0	6	5	4	5
Percent	57.14	57.14	71.43	100.00	0	85.71	71.43	57.14	71.43
4									
Total number	38	36	33	791	2	131	9	4	11
Average number per sample	9.50	9.00	8.25	197.75	0.50	32.75	2.25	1.00	2.75
Frequency	4	4	3	4	2	4	4	4	3

4	57.14	57.14	71.43	100.00	0	85.71	71.43	57.14	71.43
Total number	38	36	33	791	2	131	9	4	11
Average number per sample	9.50	9.00	8.25	197.75	0.50	32.75	2.25	1.00	2.75
Frequency	4	4	3	4	2	4	4	4	3
Percent	100.00	100.00	75.00	100.00	50.00	100.00	100.00	100.00	75.00

for 1938, that besides Hydropsychidae, the mayfly nymphs of *Paraleptophlebia* were present in every sample regardless of velocity, but as might be expected, they were most abundant at velocities of 2.00 - 2.49 feet per second. It is almost impossible, however, to determine accurately velocities in the actual habitats of the animals among the stones.

The bottom fauna data for St. Mary's River presented in this report were loaned for a student problem to Mr. S. Lee Crump, Laboratory of Limnology and Fisheries of Cornell University, Ithaca, New York, to determine statistically whether the weight of organisms could be estimated from the number of organisms in the sample; whether wet weight, determined after draining the organisms for one minute on blotting paper was a more efficient means of expressing weight of organisms than dry weight determined by drying the organisms, until thoroughly dry in an oven at 60°C., and whether an analysis of variance would show that the differences between the amounts of bottom animals in different months were real differences.

He found (1) that weight of organisms could not be estimated from the number of organisms, probably because certain large forms caused a higher weight disproportionate to the number of organisms; (2) that wet weight and dry weight are about equally efficient from the standpoint of variability; (3) that it would be possible to estimate one weight measurement from the other, if the proper factor was calculated; (4) that there were significant differences between the amounts of bottom animals in different months.

NOTES ON THE FOOD OF TROUT IN ST. MARY'S RIVER

Stomachs of 37 brook trout and 14 rainbow trout were taken from anglers' catches in St. Mary's River during the open season, May 15 to June 15, 1936, for examination. Of particular interest were (1) the numerical predominance of terrestrial over aquatic food animals, (2) the evident importance of crayfish (even of good-size) as food for small trout, (3) the presence of considerable quantities of filamentous algae in five of fourteen rainbow trout although algae were absent from all the brook trout, (4) the greater preference of the rainbow trout, as compared with the brook, for aquatic forms and (5) the presence of nematode parasites in nearly all of the stomachs. The latter may have originally been in the bodies of terrestrial insects consumed by the fish.

Of the 37 brook trout stomachs, approximately 46 per cent contained crayfish, 41 per cent contained caddis flies (all stages), 38 per cent contained stoneflies (all stages), 22 per cent contained mayflies (all stages) and 11 per cent contained fish. Not more than 8 per cent (3) contained recognizable remains of other types of aquatic food

animals not listed above. Among terrestrial animals, beetles were found in 86.5 per cent, flies in 65 per cent, ants, bees, etc., in 65 per cent, spiders in 27 per cent, grasshoppers and crickets in 11 per cent and moths or butterflies in 11 per cent. Nematode parasites were found in 97.3 per cent of the brook trout with an average of 21.3 per fish.

Of the 14 stomachs of rainbow trout, 79 per cent contained stoneflies, 57 per cent contained caddis flies, 50 per cent contained aquatic flies, midges, etc. (all stages), 36 per cent contained fish and 36 per cent contained algae. Terrestrial beetles were found in 86 per cent, terrestrial flies in 43 per cent and ants, bees, etc. in 29 per cent. Nematodes were found in only 92.9 per cent but were relatively more numerous (37.5 per fish) than in brook trout.

Metzelaar (1929), following a study of the food of 47 rainbow trout in Michigan, observed that the outstanding feature of the rainbow diet was the 15 per cent vegetation, formed largely by filamentous green algae. Surber (1936) found algae in 28 out of 131 (21.3 per cent) rainbow trout stomachs collected in 1934 from fish in Big Spring Creek, Leesburg, Virginia.

Terrestrial flies constituted 62 per cent of the number of animals found in the stomachs of brook trout (18 per fish); terrestrial beetles 16.4 per cent (4.8 per fish); ants, bees, etc., 10.7 per cent (3.1 per fish); and spiders 1.1 per cent (0.3 per fish). Among aquatic animals, caddis flies were most numerous, 3.7 per cent; stoneflies next, 2.2 per cent; and crayfish a close third, 2.0 per cent.

The food of the rainbow trout examined was more largely aquatic. Terrestrial flies constituted 45.4 per cent; terrestrial beetles, 16.9 per cent; ants, bees, etc., 3.4 per cent; aquatic flies, midges, etc., 8.2 per cent, and crayfish 2.4 per cent.

It is well that terrestrial insects make such a large contribution to the food of trout at a time when emergence of insects and freshets, or floods, reduce the supply of truly aquatic organisms.

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SUMMARY AND CONCLUSIONS

1. A study of physical conditions shows that St. Mary's River within the Big Levels Game Management Area and for a distance of at least 1 mile below the area boundary is suitable for brook trout. The maximum temperature during a year of continuous observation was 68°F. Shelter and pool conditions are probably better than average for most streams of the George Washington National Forest.
2. Chemical analysis revealed that the St. Mary's River water is very soft and averaged only 4.69 parts per million of methyl orange alkalinity in terms of calcium carbonate. It is an acid stream having an average pH of 6.8.
3. A study of temperature conditions showed that there were 231 days in a year during which temperatures ranged between 47°F. and 68°F. when trout grow and feed well. These temperature data also demonstrated that trout have little opportunity in which to grow in the spring prior to usual opening of the Virginia trout season about April 20.
4. Bottom organisms in riffle samples averaged 1.07 grams wet weight (0.25 gram dry) per square foot during the period August, 1935 to August, 1937. This amount of bottom fauna production probably represents average richness. Two of the smaller trout streams in the Big Levels Game Management Area—Kennedy Creek and Spy Creek —were also investigated at the same time. These averaged slightly higher: 1.75 and 1.80 grams wet weight per square foot, respectively. Much the same organisms occurred in the three streams. The data indicate that late spring and early summer are periods when bottom organisms are least abundant. Trout planted in the fall or early spring would find bottom foods most abundant. The severe floods of March, 1936 and April, 1937 apparently did not do protracted damage to the bottom fauna, although stream organisms averaged fewer in number during the period immediately following each flood.
5. The food found in the stomachs of 37 brook trout and 14 rainbow trout taken from anglers' catches during the period May 15 to June 15, 1936, was examined microscopically. These examinations showed (a) a numerical predominance of terrestrial over aquatic food animals, (b) that crayfish are apparently important food organisms.

(c) that rainbow trout eat quantities of filamentous algae, which brook trout do not eat, (d) that rainbow trout seem to have a greater preference for aquatic forms of food than brooks, and (e) that nematode parasites were abundant in all trout stomachs in the collection.

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Pseudoconics

D. S. DAVIS
Virginia Polytechnic Institute

A construction that permits the hyperbola, parabola, and ellipse to be derived from a circle can be altered slightly so that new curves that are not conic sections result. Equations of such pseudoconics, substantiated by analytical proofs, are presented.

CONICS

In a previous paper the author (1950) showed that the hyperbola, parabola, and ellipse could be derived from the circle by simple variations of a general method of construction. In accordance with this method, draw a circle (Figure 1) of center C and at any point O on a diameter with extremities A and N erect a perpendicular to AN. Connect O with any point M on the circumference and draw MS parallel to AN. The locus of P, the intersection of OM and SN, is

(1) an hyperbola when O lies between the center C and N
(2) a parabola when O and C coincide, as in Figure 1, and
(3) an ellipse when O lies between A and C.

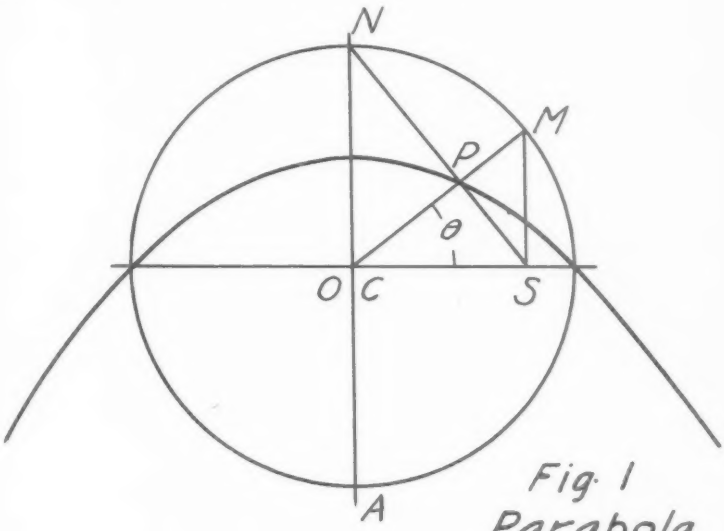


Fig. 1
Parabola

PSEUDOCONICS

When O does not lie on the diameter AN, new and interesting curves result from a construction otherwise identical to that of the general method just described. In accordance with this procedure, draw a circle (Figures 2, 3, 4, and 5) of center C and radius a and draw a diameter AN. From any point O not on AN draw a perpendicular to AN at T. Connect O with any point M on the circumference and draw MS parallel to AN. Draw OM and NS, which intersect at P, producing these lines if necessary. Then study the locus of P.

La Tosca, Figure 2

When O lies on a line perpendicular to AN at the center C and at a distance of $a\sqrt{2}$ from C, the locus of P becomes the curve designated as La Tosca.

For the triangle COM, let $\angle COM = \theta$. Then

$$(OM)^2 + (OC)^2 - 2(OM)(OC)\cos\theta = (CM)^2,$$

which, on substitution of R for OM and $a\sqrt{2}$ for OC, becomes

$$R^2 + 2a^2 - 2Ra\sqrt{2}\cos\theta = a^2 \text{ or}$$

$$R^2 - 2Ra\sqrt{2}\cos\theta + a^2 = 0,$$

the equation of the circle in polar coordinates of origin O. Solving for R,

$$R = a(\sqrt{2}\cos\theta \pm \sqrt{2\cos^2\theta - 1}) \quad (1)$$

$OP = OM + MP$, which becomes $r = R + MP$ (2)

when OP is replaced by r.

In the similar triangles PMS and PQN,

$$\frac{MP}{QP} = \frac{MS}{QN}, \text{ from which } MP = \frac{(MS)(PQ)}{QN} \quad (3)$$

$$MS = R\sin\theta \quad (4)$$

$$QN = QC + CN = OC\tan\theta + a = a\sqrt{2}\tan\theta + a$$
$$= a(1 + \sqrt{2}\tan\theta) \quad (5)$$

$$QP = r - OQ = r - OC/\cos\theta = r - a\sqrt{2}/\cos\theta$$
$$= \frac{r\cos\theta - a\sqrt{2}}{\cos\theta} \quad (6)$$

Substitution of equations 4, 5, and 6 in equation 3 yields

$$MP = \frac{R\sin\theta\,(r\cos\theta - a\sqrt{2})}{a\cos\theta\,(1 + \sqrt{2}\tan\theta)}$$
$$= \frac{R\tan\theta\,(r\cos\theta - a\sqrt{2})}{a(1 + \sqrt{2}\tan\theta)} \quad (7)$$

Substitution of equation 7 in equation 2 results in

$$r = \frac{aR}{a(1 + \sqrt{2}\tan\theta) - R\sin\theta} \quad (8)$$

the equation of La Tosca in polar coordinates. (For convenience in printing, R from equation 1 is not substituted in equation 8.)

The equations of the curves of Figures 3, 4, 5, and 6 were derived

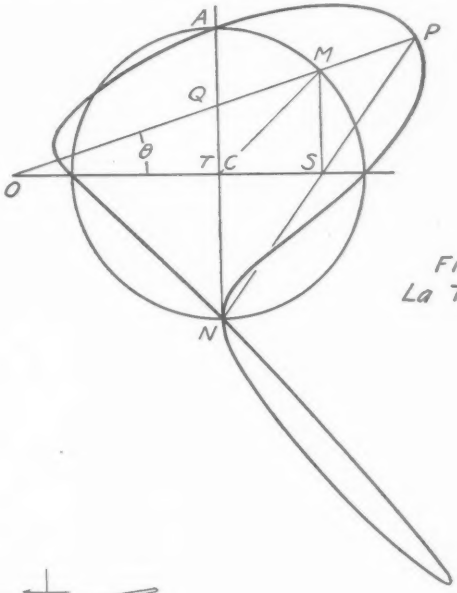


Fig. 2
La Tosca

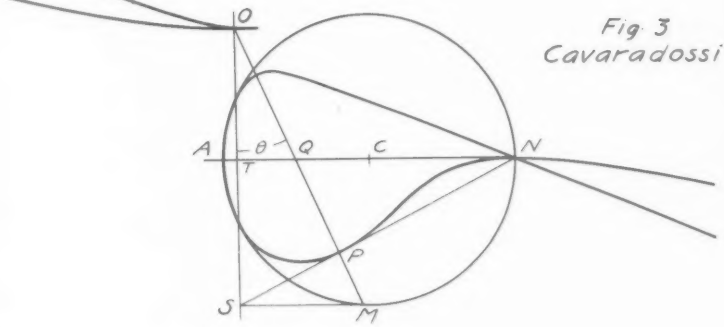


Fig. 3
Cavaradossi

in a similar manner. For three other positions of the center C, the following material presents the coordinates of that point, the equations of the circles, and the equations of the curves, all with respect to O as the origin.

Cavaradossi, Figure 3

Coordinates of C: $0.9\ a\ \sqrt{2},\ -\pi/4$.

$$R = a[0.9\sqrt{2}\cos(\theta + \pi/4) \pm \sqrt{1.62\cos^2(\theta + \pi/4) - 0.62)}\ ]$$

$$r = \frac{1.9\ a\ R\ \tan\theta}{a(1.9\ \tan\theta + 0.9) + R\ \sin\theta}$$

Boccanegra, Figure 4

Coordinates of C: $\frac{a\sqrt{10}}{2}$, $\tan^{-1}(-1/3)$.

$$R = \frac{a\sqrt{2}}{2}[\sqrt{5}\cos(\theta - a) \pm \sqrt{5\cos^2(\theta - a) - 3}\ ] \text{ where}$$

$$a = \tan^{-1}(-1/3)$$

$$r = \frac{a\ R}{a(1 - 3\ \tan\theta) + 2\ R\ \sin\theta}$$

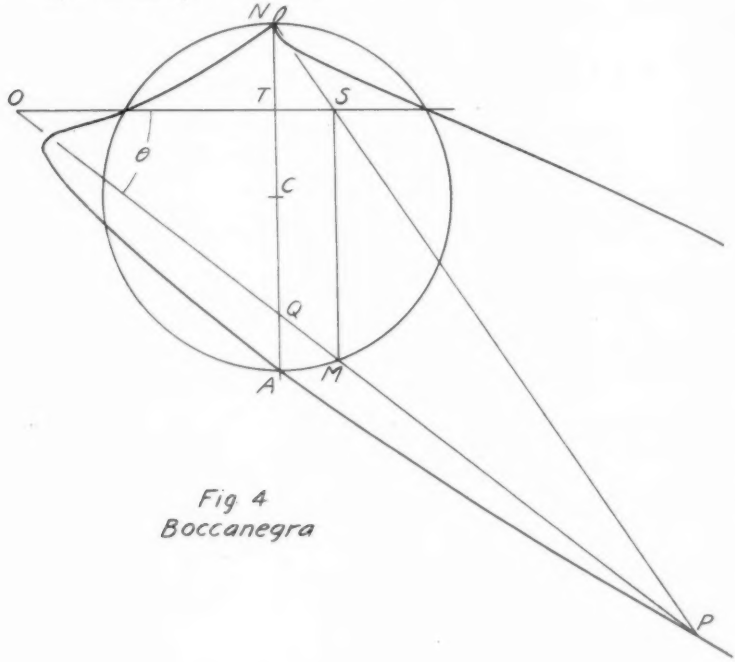


Fig 4
Boccanegra

Amelia, Figures 5 and 6

Coordinates of C: $\frac{a\sqrt{2}}{2}, -\pi/4$.

$$R = \frac{a\sqrt{2}}{2}[\cos(\theta + \pi/4) \pm \sqrt{\cos^2(\theta + \pi/4) + 1}\,]$$

$$r = \frac{a\,R}{a(1 - \tan\theta) + 2\,R\sin\theta}$$

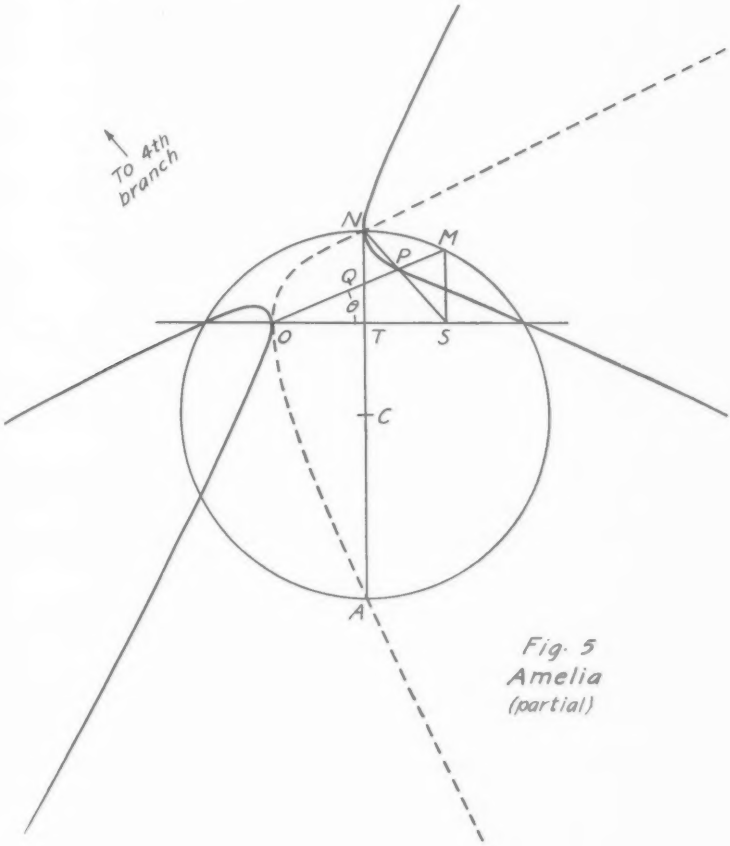


Fig. 5
Amelia
(partial)

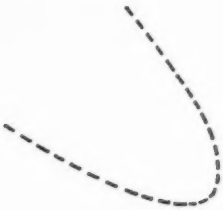
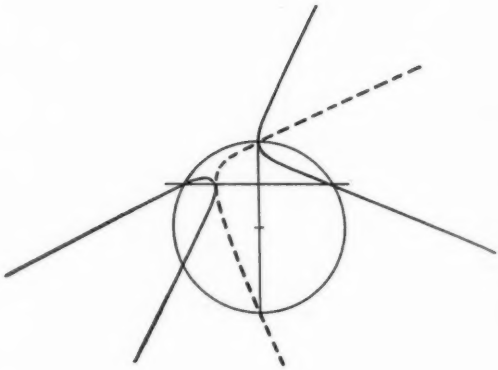


Fig. 6
Amelia
(complete)



GENERAL OBSERVATIONS

The curve of Figure 2 appears as two loops. That of Figure 3 exhibits two branches with a very small section that is not truly a loop, as shown in the enlargement. The curve of Figure 4 shows one small loop and one very large one. Figure 5 presents three branches and indicates a fourth; all four appear in Figure 6, drawn to a smaller scale.

Although a cone cannot be cut by a plane in such a manner as to yield any of the curves of Figures 2 to 6, inclusive, they were constructed by a general method closely enough related to that for the conic sections to entitle the new curves to be considered as pseudoconics. These pseudoconics provide stimulating exercises in mechanical drawing for the curious student and confront him, at some points, with puzzling procedures. Near O in Figure 3, for example, the student must decide whether the upper and lower parts of the curve cross or are tangent. The derivations of the equations afford unique applications of analytical geometry and demonstrate the desirability of exercising care with respect

to the signs of the trigonometric functions. Teachers of mechanical drawing and analytical geometry may find these constructions and proofs of interest as supplementary material because of the challenges they offer.

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Premenstrual Tension

WILLIAM BICKERS
Medical Arts Building, Richmond, Virginia

There can be little doubt that the symptoms of premenstrual tension are related to abnormal water metabolism. Thomas (1933) reported two cases of unusual edema recurring cyclically during the premenstrual period. Associated with the edema were severe headache, coma, abdominal fullness, leg pains, and other classical symptoms which are now grouped under the clinical diagnosis of premenstrual tension. Thomas observed that all these symptoms disappeared following the diuresis which occurred at the time of menstruation. Greenhill and Freed (1941) first called attention to the frequency of the syndrome and related it to abnormal water retention. Many theories have been advanced to explain the physiologic mechanism of this abnormal water storage; however, none of them is completely satisfactory.

The syndrome of premenstrual tension can be reproduced in part during the corpus luteum phase of the cycle, by the daily administration of Pitressin, the vaso-pressor substances of the posterior pituitary. In a group of 16 patients the syndrome was reproduced clinically and pathologically by the daily administration of Pitressin in a dose of 10 units daily. Water storage up to 4 lbs. was artifically induced in some of these patients.

A recent clinical study on 22 patients with severe premenstrual tension showed an average premenstrual weight gain of 6.8 lbs, while normal women with no premenstrual symptoms gain less than 2.5 lbs. In this group the intensity of symptoms varied directly with the amount of weight gained and this paralleled closely the volume of water lost during the first day of menstruation. There can be little doubt that the essential pathologic physiology involved in the production of this syndrome was water retention. In these 22 patients water-loss without treatment during the first 24 hours of menstruation averaged 3270 cc. while asymptomatic patients excrete about 1700 cc. Premenstrual tension is essentially a water toxemia. The endocrine disturbances leading to this deranged water metabolism are yet unknown.

STUDY OF WATER AND CHLORIDE METABOLISM ON RATS

When rats are fed measured amounts of water and placed in a metabolism cage it is possible to recover 104% of the administered water during a four hour collection period, water itself being something of a diuretic. When Pitressin in a dose of 0.5 unit per rat is administered subcutaneously to the animal 37% of the administered water is recovered in 4 hours. To measure the diuretic effect of a drug to be employed in premenstrual tension it is satisfactory to induce water storage in an animal by the administration of Pitressin, employing a modification of the technique described in the British Pharmacopoeia (1948). This method simulates the water retention of the premenstrual tension. When Pyrilamine 8 Bromo Theophyllinate in a dose of 0.1 gm./kg. orally is administered to the rat along with 5 cc. of water per 100 gm. of body weight and Pitressin in a dose of 0.5 unit subcutaneously the antidiuretic effect of the Pitressin is more than neutralized. This is shown by a recovery of 92% of the administered water in the 4 hours as compared to 37% recovery when water and Pitressin alone were given. When the experiment on rats was repeated using ammonium chloride in a dose of 0.1 gm./kg., instead of the Pyrilamine 8 Bromo Theophyllinate compound, only 34% of the administered water was recovered in 4 hours; essentially the same as if water and Pitressin alone were given.

These figures were obtained from a series of experiments and in each experiment 4 rats in a single cage were employed. Water in the same volume, 5 cc./100 gm. body weight, was used in a group of rats which also received 0.5 unit of Pitressin subcutaneously and testosterone intramuscularly. The hormone was administered as testosterone propionate in a dose of 5 mg. intramuscularly given at 4 P. M. on the day preceding the test and repeated at test time on the following day. Water recovery in this group of animals was 23%.

Chloride excretion, as measured by the Volhard-Arnold method, was studied in each group of animals along with the quantitative determination of water recovery. Those animals which received water alone excreted an average of 24 mg. of total chlorides per cage of 4 rats in 4 hours. The animals that received water and Pitressin excreted 68 mg. while those to which water, Pitressin, and ammonium chloride were given excreted 82 mg. (figure uncorrected for chloride administered). The rats treated with water, Pitressin, and testosterone yielded an average of 52 mg. of total chlorides per cage in 4 hours. The rats which received water, Pitressin, and Pyrilamine 8 Bromo Theophyllinate yielded an average of 102 mg. per cage during the same interval. (See table 1).

TABLE 1.—Table of Water and Total Chlorides Excretion

The Male Rat

(4 hour test period)

	Recovery Average % Water	Average Total Chlorides per Cage of 4 rats
Water	104	24mg.
Water, Testosterone	112	28
Water, Ammonium Chloride (0.1 gm./kg. orally)	91	....
Water, Pyrilamine 8 Bromo Theophyllinate (0.1 gm./kg. orally)	136	68
Water, Pitressin	37	68
Water, Pitressin, Testosterone	23	52
Water, Pitressin, Ammonium Chloride 0.1 gm./kg. orally	32	82
Water, Pitressin, Ammonium Chloride 0.5 gm./kg.	75	73
Water, Pitressin, Pyrilamine 8 Bromo Theophyllinate 0.1 gm./kg. orally	92	102

STUDY OF WATER AND CHLORIDE METABOLISM ON HUMANS

Three hospitalized young women volunteered to cooperate in a study of water and chloride metabolism. These patients were aged 22, 27, and 32 respectively. They were patients who had been subjected to no surgical trauma and who had no serious medical or surgical illness. They received no food or water intake after 9 p.m. On the following morning each patient was given 1,000 cc. of tap water orally over a period of 30 minutes. At the same time each patient received 10 units of aqueous Pitressin subcutaneously. The bladder was emptied by catheacrization before taking the water and the catheter left in place and connectd with a bedside bottle. The urine was collected over a period of 4 hours. During this period the patients excreted 106 cc., 275 cc., and 210 cc. respectively. The 3 patients were then allowed a regular diet until the evening, and at 9 P.M. all food and fluid were withheld. On the next morning each of the three patients received 1,000 cc. of tap water orally and 10 units of aqueous Pitressin subcutaneously. In addition each was given Pyrilamine Bromo Theophyllinate in a dose of 100 mg. orally during the period of water ingestion. The dose was repeated 2 hours later and urine was collected from an indwelling catheter over a 4 hour period. The urine excreted was 950 cc., 980 cc.,

Water—5 cc/100 gm. body weight, orally.
Pitressin—0.5 unit/rat, s.c.
Testosterone Propionate—5 mg. at 4 P.M. day preceding test, and again at test time, i.m.

and 1,200 cc. respectively for each of the 3 patients. It is apparent from these figures that Pyrilamine 8 Bromo Theophyllinate was able to neutralize almost completely the water storage effect of Pitressin. (See table 2).

TABLE 2.—Table of Water Excreted

The Human Female

(4 hour test period)

	Water, Pitressin	Water, Pitressin, and Pyrilamine 8 Bromo Theophyllinate
Patient 1	106 cc.	950 cc.
Patient 2	275 cc.	980 cc.
Patient 3	210 cc.	1200 cc.

CONCLUSIONS

1. Premenstrual tension is a symptom-complex related to abnormal water storage during the premenstrual period. It is essentially a water toxemia. Intensity of symptoms vary directly as the amount of water retained. Relief of symptoms accompany the diuresis which usually occurs on or about the first day of menstruation. Symptoms are severe when premenstrual weight gain exceeds 5 pounds.
2. The etiology of the disturbed water metabolism is unknown but appears to be related to some Pitressin-like toxin.
3. In a group of 22 patients with severe symptoms the average weight gain was 6.8 pounds. Symptoms were prevented when the weight gain was prevented by blocking the water fixing toxin of the premenstrual period. The most effective agent for blocking the water storage was found to be Pyrilamine 8 Bromo Theophyllinate.
4. Pitressin-induced edema in rats could not be unblocked by testosterone or ammonium chloride but was unblocked by the Pyrilamine 8 Bromo Theophyllinate compound.
5. Pitressin-induced edema in 3 human females was effectively unblocked by the Pyrilamine 8 Bromo Theophyllinate compound.

Water—1,000 cc. /patient.
Pitressin—10 units /patient, s.c.
Pyrilamine 8 Bromo Theophyllinate
100 mg. 8:15 A.M. day of test.
100 mg. again at 10:15 A. M., orally

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Survey of the Intestinal Helminths of *Triturus v. viridescens* in the Vicinity of Charlottesville, Virginia[1]

CATHERINE M. RUSSELL

Miller School of Biology, University of Virginia

This report is based on a survey of the helminths occurring in the intestinal tract of the newt, *Triturus v. viridescens*, (Rafinesque), in the vicinity of Charlottesville, Albemarle Co., Virginia. This survey extended over a period from May, 1950 to May, 1951. In addition to ascertaining what intestinal parasites were present, observations were made on their frequency of occurrence and distribution in the host.

In May, 1950, the survey was begun. Monthly collections were made from ponds in and around Charlottesville, Virginia, namely: the Old Reservoir located on the north side of Jefferson Mountain; a pond at Sunnyside, on the estate of C. C. Duke, Esq., which is located 1.4 miles west on Barracks Road beyond the intersection of Barracks Road and Route 29; and the Old Fish Hatcheries, two miles south of the city limits of Charlottesville, on Route 29. Seventy-five or more newts were collected monthly with the exception of August and December. During these months some difficulties were encountered; in August, when collections were made the water in the ponds was at unusual levels; in December, the water was frozen; therefore, only a limited number of animals was obtained.

Salamanders were examined the day they were collected, if possible; otherwise, they were stored in the refrigerator (4°-5° C.). *Triturus v. viridescens* shows a decrease in the number of parasites present if kept at room temperature for several days or more. However, it has been observed that at a temperature of 4°-5° C. there is little, if any, such decrease.

The salamanders were anaesthetized in a 1 : 500 dilution of Tricaine Methane Sulfonate (MS 222, Sandoz), decapitated, and the intestinal tracts were removed and placed in 0.6% NaCl. The helminths were counted and identified as the tract was dissected and notation was made as to the region of the gut in which the parasites were found. All helminths were kept in 0.6% NaCl and rechecked after each series of dissections, where necessary whole mounts were prepared and studied.

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[1] Contribution from the Miller School of Biology, University of Virginia. Part I of a dissertation submitted in candidacy for the Ph.D. degree.

TABLE 1

Actual Number and Percentage of Intestinal Helminths in Triturus v. viridescens, May, 1950 to May, 1951, Charlottesville, Va.

Date of collection	Triturus v. viridescens		Plagitura parva		Plagitura salamandra		Megalodiscus rankini		Brachycoelium hospitale		Nematoda sp.		Cestodaria sp.	
	No. Examined	% Infected	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
5/1950	100	45.0	7	7.0	14	14.0	80	20.0	3	2.0	25	10.0	0	0.0
6/1950	75	17.4	2	2.6	6	8.0	70	13.0	7	2.6	12	2.6	0	0.0
7/1950	125	72.0	0	0.0	31	15.2	253	46.4	21	6.4	13	22.4	0	0.0
8/1950	52	19.3	2	3.8	5	5.7	0	0.0	4	6.6	0	0.0	0	0.0
9/1950	131	40.5	0	0.0	18	8.3	59	17.5	0	0.0	24	18.3	0	0.0
10/1950	92	51.1	15	6.5	70	27.1	23	7.6	7	6.5	14	6.5	0	0.0
11/1950	173	46.9	15	5.7	95	17.8	161	23.1	29	2.3	18	8.6	0	0.0
12/1950	20	60.0	3	10.0	7	25.0	0	0.0	7	5.0	4	5.0	0	0.0
1/1951	75	57.4	9	6.6	12	14.6	51	20.0	4	5.3	33	18.6	0	0.0
2/1951	140	61.5	13	12.1	60	27.1	129	25.0	19	4.2	98	20.7	0	0.0
3/1951	300	66.7	108	17.0	170	18.0	529	51.0	13	2.6	37	7.1	0	0.0
4/1951	75	53.0	18	9.5	31	19.1	57	26.0	8	6.8	19	10.9	2	2.6
Total and Average %	1,358	49.2	192	6.7	519	16.6	1,412	20.8	122	4.2	297	10.8	2	0.2

Grand Total of Parasites 3,902

Table I shows that 1,358 salamanders were examined. There, too, it is observed that many specimens of the class Trematoda and Nematoda were found together with two specimens of the subclass Cestodaria. The species of trematodes were:

PLAGIORCHIIDAE

Plagitura parva Stunkard, 1933.
Plagitura salamandra Holl, 1928.

PARAMPHISTOMATIDAE

Megalodiscus rankini[2] Hollis, 1941.

BRACHYCOELIIDAE

Brachycoelium hospitale Stafford (1900) 1903.

The cestodarians, of which no specific identification has been made, have not been reported previously from *Triturus v. viridescens*. Similar forms have been reported frequently from fish and reptiles.

The nematodes which were found embedded in the mucosal wall have not as yet been identified.

Plagitura parva and *P. salamandra* were found in the intestinal tract from the duodenum to the rectum. *Megalodiscus rankini* was found generally in the rectum; however, in the July, 1950, collections they were found throughout the digestive tract from the esophagus to the rectum. *Brachycoelium hospitale* characteristically enough was located in the duodenum. The nematodes were generally situated in the region of the mid-gut. Ocassionally, they were found in the lower intestinal tract. The cestodarians appeared to occupy the entire small intestine.

It is of interest to compare the helminth infections of *Triturus v. viridescens* collected in April, 1951, from the vicinity of Duke University, North Carolina with those collected near Charlottesville, Virginia in the same month.

Fifty salamanders from North Carolina were examined.[3] Of these 70% were infected. The actual number of helminths and percentage of infection were recorded as follows:

---

2 **Megalodiscus rankini** as described by Hollis differed from the specimens mentioned above mainly in size. She found the average (based on 16 specimens) length to be 2 mm. (minimum of 1.68 mm. and maximum of 2.3 mm.) while the specimens from Charlottesville averaged (based on 25 specimens) 1.5 mm. in length (minimum of 1.3 mm. and maximum of 1.6 mm.). Specimens obtained from the type locality (vicinity of Duke University, N.C.) agreed in size with those from Charlottesville, Va. Those specimens upon which the species description was based were obtained from Dr. Rankin, who while making an ecological study of parasites of some North Carolina salamanders, happened to save some of these trematodes. It is conceivable that he saved the largest ones of the group.

3 In this collection one **Diplodiscus temperatus** Stafford 1905 was found. **Diplodiscus temperatus** has been found in salamanders from Charlottesville, Va., though not from any included in this survey.

TABLE II

Distribution of Helminth Infection of Triturus v. viridescens for each month of the year - 1950-51

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Plagitura parva												
Maximum	1	1	0	1	0	3	2	1	3	3	8	8
Minimum	1	1	0	1	0	1	1	1	1	1	1	1
Average	1	1	0	1	0	2.5	1.5	1.1	1.5	1.1	2.1	2.5
Mode	1	1	0	1	0	2	1	1	1	1	1	1
Plagitura salamandra												
Maximum	1	1	6	1	3	7	13	4	3	11	8	8
Minimum	1	1	1	1	1	1	1	1	1	1	1	1
Average	1	1	1.7	1.6	1.7	2.8	3.0	1.4	1.1	1.8	2	2.2
Mode	1	1	1	1	1	2	2	2	1	2	1	2
Megalodiscus rankinii												
Maximum	13	14	20	0	5	11	11	0	13	15	19	9
Minimum	1	1	1	0	1	1	1	0	1	1	1	1
Average	4	7	4.3	0	2.5	2.2	4.0	0	3.4	3.6	3.4	3.0
Mode	1	2	1	0	2	2	1	0	1	2	2	2
Brachycoelium hospitale												
Maximum	1	2	2	1	0	2	6	7	1	6	4	3
Minimum	1	1	1	1	0	1	1	7	1	1	1	1
Average	1.5	1.1	2.6	1.3	0	1.1	4.8	7	1	3.1	1.6	1.6
Mode	1	1	1	1	0	1	2	7	1	3	1	1
Nematoda sp.												
Maximum	3	3	4	0	4	4	3	4	6	10	3	4
Minimum	1	1	1	0	1	1	1	4	1	1	1	1
Average	2.5	3.0	2.1	0	1.6	2.3	1.2	4	2.3	3.3	1.6	2.3
Mode	2	2	1	0	1	1	1	4	3	2	2	2

	P. parva		*P. salamandra*		*M. rankini*		*Nematoda*		*B. hospitale*	
	No.	%	No.	%	No.	%	No.	%	No.	%
N. Carol.	19	26	14	28	4	8	69	34	25	18
Virginia	18	9.5	31	19.1	57	26	19	10.9	8	6.8

In Table I it is observed that *Megalodiscus* provides the greatest percent of infection as well as yielding the greatest number of worms. They seem to have two major peaks of infectivity, one in March, the second in July. *Plagitura parva* and *P. salamandra* appear to be more common in the fall, winter and spring months.[4] The nematodes and the *Brachycoelium* appear to have no peaks of seasonal occurence.

Table II presents a resume of the maximum, minimum, mode and average number of worms of each species of worm (except cestodaria) during the twelve months period. Here it is noticed that *Megalodiscus* shows the highest incidence of infection per individual with *Plagitura salamandra* and the nematode following.

SUMMARY AND CONCLUSIONS

A total number of 3,902 parasites were found in the intestinal tract of 1,358 *Triturus v. viridescens*, examined from May, 1950 to May, 1951. During this period the following helminths with their respective average percentages of infection were found: Cestodaria (0.2%), *Brachycoelium hospitale* (4.2%), *Plagitura parva* (6.7%), Nematoda (10.8%), *Plagitura salamandra* (16.6%), *Megalodiscus rankini* (20.8%). Cestodarians are reported for the first time from *Triturus v. viridescens*.

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4 There are some data available which would indicate a possible correlation between the life cycle of the snail host and that of the adult fluke.

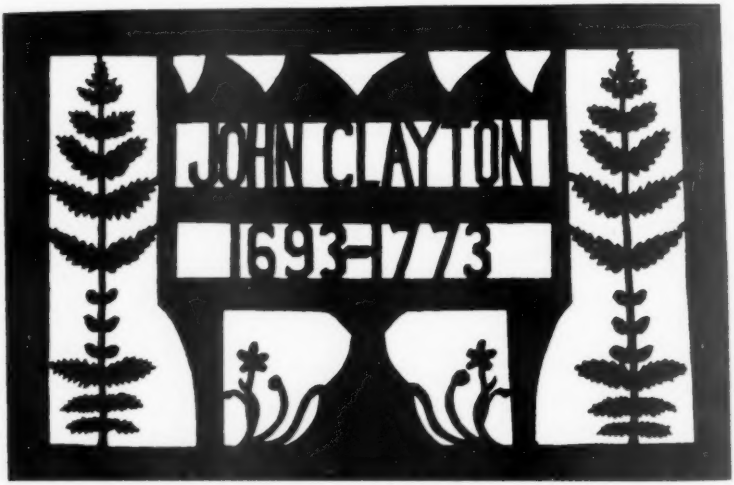
News and Notes

(Editor's note: News contributions should be sent to the person whose name appears at the end of the appropriate section.)

IN MEMORY OF JOHN CLAYTON, BOTANIST OF COLONIAL VIRGINIA

JESSIE HOPKINS AND A. B. MASSEY

Of the several botanists in Colonial America, John Clayton of Virginia was outstanding. He contributed much to botany, especially that of eastern Virginia. The book, *Flora Virginica,* published by Gronovius of Leyden was based upon plant collections and notes made by John Clayton. This book appeared in three editions; dated 1739, 1745, and 1762. It was the outstanding botanical publication of the period.



PHOTOGRAPH OF WROUGHT IRON MARKER PLACED AT ENTRANCE TO JOHN CLAYTON'S COLONIAL HOME NEAR SOLE, VIRGINIA.

In Virginia, Clayton's memory has been honored in several ways. The Mountain Lake Biological Station, established by the University of Virginia, near Mountain Lake, Giles County, Virginia, dedicated one of its buildings to him. The flora committee of the Virginia Academy of Science for several years published the journal, *Claytonia,* commemorat-

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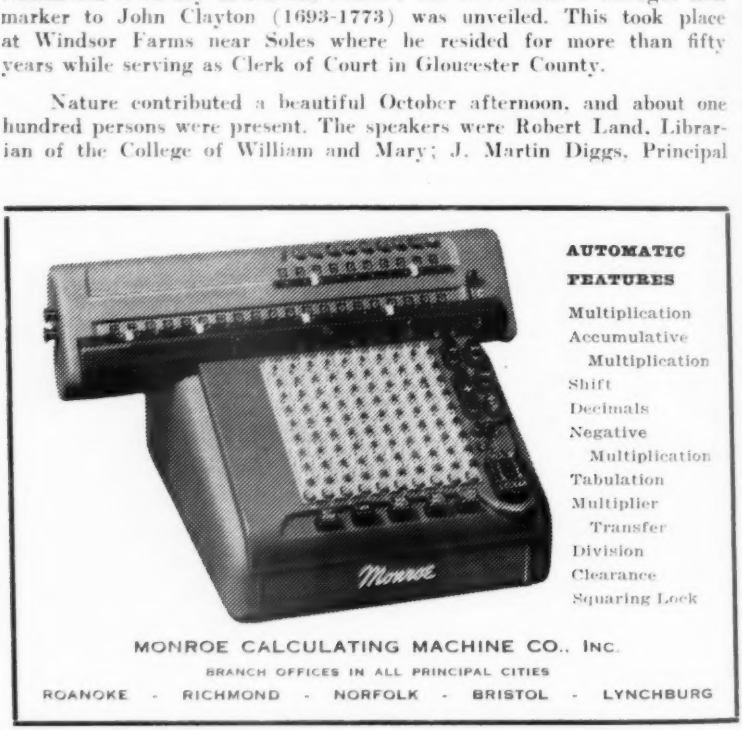
ing John Clayton. The biological club of the College of William and Mary has honored John Clayton and the late Professor Grimes by naming itself the Clayton-Grimes Biological Club.

The Misses Georgia Mogford and Jessie Hopkins of Cardinal, in Mathews County (formerly a part of Gloucester County), realizing that the site of John Clayton's former home and the region in which he collected intensively had never been indicated, took steps to develop and place an appropriate marker at Clayton's former home site. Appropriate exercises were held when the marker was placed on the afternoon of October 14, 1950. Miss Hopkins supplies the following description of the dedication exercises:

Many months of painstaking research on the part of Miss Georgia Mogford, a member of the Mathews County, Virginia, Garden Club, culminated Saturday afternoon, October 14, 1950 when a wrought iron marker to John Clayton (1693-1773) was unveiled. This took place at Windsor Farms near Soles where he resided for more than fifty years while serving as Clerk of Court in Gloucester County.

Nature contributed a beautiful October afternoon, and about one hundred persons were present. The speakers were Robert Land, Librarian of the College of William and Mary; J. Martin Diggs, Principal



of our local Lee Jackson School; and Clyde Eddy, explorer, lecturer, and author, from New York City. Mr. Eddy reviewed the life and work of Clayton. Miss Mogford conducted the meeting. The marker was unveiled by little Branda and Charles Armistead, grandchildren of Mrs. Nathaniel Leigh who now owns the farm which was the home of John Clayton.

Mr. Robert Land spoke of "Why Virginians Should Know John Clayton," and he very thoughtfully brought with him a copy of Clayton's *Flora Virginica,* from the library of the College of William and Mary. Mr. Diggs told us of the botanical work done by John Clayton. He quoted Jefferson as saying that John Clayton was probably the most painstaking and accurate of all the colonial botanists, and that he was closely in touch with the Indians both in language and herbal knowledge. Mr. Eddy said it was time we rediscovered Clayton, and he paid tribute to Miss Georgia Mogford for her untiring efforts to have a marker placed at the entrance of his former home which is now in Mathews County, having been separated from Gloucester County in 1791. Mr. Eddy also highly complimented Miss Jessie Hopkins who designed the marker. Spring beauty (*Claytonia virginica*) and the interrupted fern (*Osmunda claytoniana*), two of the plants which botanists have named in honor of John Clayton, appear in the design. The marker is hung from a branch of an old *Catalpa* tree which is said to be an outgrowth from a very old tree which was on the site as long ago as anyone can remember; one of a line of such trees marking the entrance to Clayton's home.

Mr. Diggs later sent to the Garden Club several blossoms of the turtle head (*Chelone obliqua*) which Clayton reported. The real identity of this *Chelone* was uncertain until it was rediscovered near Clayton's home by Dr. E. T. Wherry about one hundred seventy-five years later. It is a most striking and beautiful flower. As yet, the purple fringe tree which Clayton described has not been found.

Clayton's farm, which history says contained over four hundred acres, comprises rolling ground which is still very rich soil. Through it runs a fine brook where probably his collections of water-loving plants grew. The walled garden outline has long since become the dusty part of a field now being cultivated. Some of the foundation of his home is buried well under the surface of the ground, marked only by the crumbling bricks. From a photostatic copy of an old fire insurance record found by Mrs. Polly Mason and in her book collection of copies of old deeds, we got a very good description of the house and its plan of building.

Mr. Bernard Mikula, a member of the Clayton-Grimes Biological Club of the College of William and Mary, brought to the meeting a fine plant of the *Osmunda claytoniana* which will be the first plant to

be placed at the entrance to the Clayton farm.

In Mathews County, Virginia at the junction of Route 14 (road to Gloucester C. H.) and Windsor Road which passes Windsor Farms, a state historical marker will soon be placed. This is being done through the interest of the late Dr. Donald W. Davis of the College of William and Mary, and Dr. E. G. Swem, Librarian Emeritus of the College.

SECTION NEWS

AGRICULTURAL SCIENCE SECTION

During the past year, Mr. C. I. Rich, Mr. John D. Pendleton, and Mr. Arthur Sherrell have been appointed to the Agronomy Department staff at the Virginia Polytechnic Institute. Mr. Rich returned to Blacksburg after being on leave of absence for two years securing his doctorate degree at the University of Wisconsin. He will be in charge of fundamental research in soil fertility dealing with soil and plant analysis. Mr. Pendleton, who was on leave of absence for two years securing his doctorate degree at Cornell University, returned this past September to resume his duties on the teaching staff of the department. Mr. Sherrell, a graduate in agronomy at Virginia Polytechnic Institute, was employed as assistant agronomist, and assigned to soil survey duties in the State.

Mr. M. M. Parker, assistant director of the Virginia Truck Experiment Station at Norfolk, Va., was declared Virginia's "Horticulturist of the Year" by the Horticultural Club of the Virginia Polytechnic Institute. The recognition was for Mr. Parker's contributions to horticulture in Virginia, specifically for his work on kale, collards, spinach, potatoes, and strawberries.

The resident instruction staff of the Agricultural Engineering Department, Virginia Polytechnic Institute, have been preparing information for inspection by the Engineering Council for Professional Development, the recognized accrediting agency for engineering curricula.

Mr. James H. Bywaters and Mr. Clayton E. Holmes, of the Poultry Department, Virginia Polytechnic Institute, report that preliminary studies of the use of Vitamin B_{12} and antibiotic substances have shown very favorable results so far as growth response is concerned. There are indications that their use will allow for more efficient uses of proteins from vegetable sources and a marked saving in the amounts of protein from animal and marine sources needed for growing chickens.

A new green house range, shared by the Departments of Horticulture, Agronomy, Plant Pathology and Physiology, Biology, and Entomology, at the Virginia Polytechnic Institute was completed this past year. This establishment includes a brick service building containing offices, a laboratory-classroom, and storage space. The green houses, covering some 20,000 square feet of area, are equipped for automatic control of heat and Ventilation. Several different types of benches are included such as V-bottom concrete benches for subirrigation plant

culture, conventional wood benches, and ground beds.—T. J. NUGENT, Box 2160, NORFOLK, VIRGINIA

ASTRONOMY, MATHEMATICS, AND PHYSICS SECTION

Two members of this section will go on leave to pursue further graduate study at the University of North Carolina in the coming academic year. They are Mr. A. D. Campbell of Hampden-Sydney, and Mr. E. C. Wingfield of the University of Richmond.

Mr. Victor L. Klee of the Mathematics Department of the University of Virginia has received a National Research Council Fellowship and will be on leave at the Institute for Advanced Study for the session 1951-1952.

Ground has been broken for the new Science Hall at the Virginia Military Institute. This building will house the Department of Physics and certain others.

Rouss Physical Laboratory of the University of Virginia has been awarded a Dupont Research Fellowship in Physics for the coming academic year. The U. S. Rubber Fellowship at Rouss will be held by Mr. J. M. Watkins.

Mr. Jack Williams will join the staff of the Physics Department

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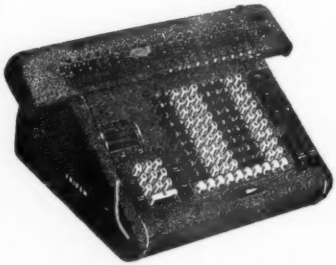

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at the University of Richmond for the coming year. Mr. Williams is a graduate of the University of Richmond and the University of North Carolina.

Mr. D. Rae Carpenter has been appointed to the Physics staff at the Virginia Military Institute for the session 1951-52. Mr. Carpenter holds degrees from Roanoke College and Cornell University.

I. G. FOSTER, VIRGINIA MILITARY INSTITUTE

CHEMISTRY SECTION

In recognition of achievement and distinction in her chosen field, Miss Nan V. Thornton has been selected to give the alumnae address at the commencement exercises at Randolph-Macon Woman's College, where she is professor and head of the department of chemistry.

Mr. Harold H. Garretson, professor of chemistry at Lynchburg College, has been appointed Research Participant in the Materials Chemistry Division of the Oak Ridge National Laboratory. He has been granted sabbatical leave of absence from the college for fifteen months.

Mr. Allan T. Gwathmey was Sigma Xi Lecturer before the Virginia Polytechnic Institute chapter on May 4.

"In recognition of achievements in pre-medical education," three professors of chemistry were made honorary members of the Phi Psi chapter of Phi Beta Pi, medical fraternity at the Medical College of Virginia. The honorees were Messrs J. F. Baxter, of Washington and Lee University, Ashley Robey, of Roanoke College, and J. W. Watson, of Virginia Polytechnic Institute.

Mr. Lynn D. Abbott, Jr., associate professor of biochemistry at the Medical College of Virginia, attended April 12-14, the Fourth Annual Spring Research Conference sponsored by the Biology Division of the Oak Ridge National Laboratory, supported by the Atomic Energy Commission. Subjects discussed had to do with "The Effects of Radiation at the Cellular and Physiological Levels."

The Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, March 5-7, was attended by Messrs. James W. Cole, Everett C. Cogbill, Ralph H. Thiers, and John H. Yoe, from the University of Virginia.

Mr. Earl W. Nelson has joined the Development Department of the Piney River Plant of the Calco Chemical Division of the American Cyanamid Company. Mr. Nelson received the Ph.D. from Purdue in 1936. He was formerly employed by the New Jersey Zinc Company.

John C. Forbes, Professor of research biochemistry at the Medical College of Virginia, presented a paper at a meeting of the International

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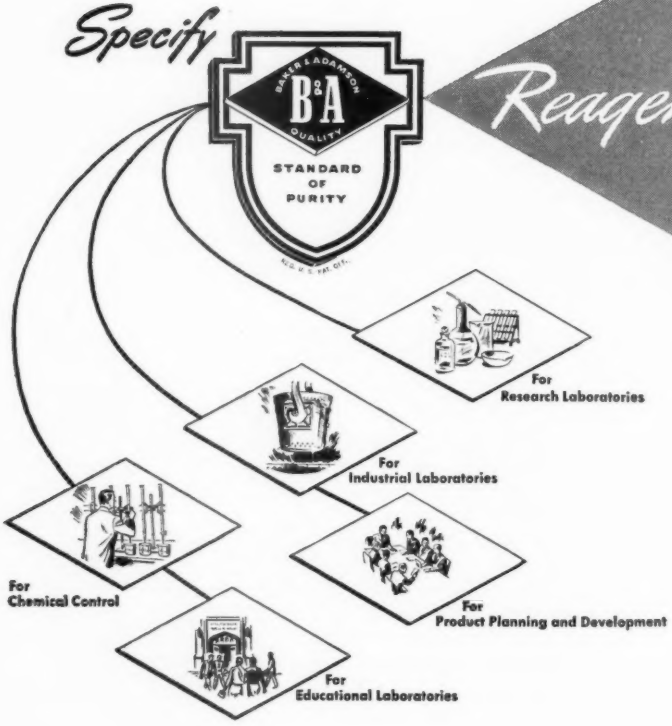

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Association for Dental Research in French Lick, Indiana, on March 19. The title of his paper was "Effect of Various Metallic Salts on the Production of Acid by Saliva Containing Fermentable Sugars." This investigative work was carried on in cooperation with Dr. J. Doyle Smith, Associate Professor of organic chemistry at the College.

Correction: Mr. Lyndon F. Small is Chief of the Laboratory of Chemistry in the National Institute of Arthritis and Metabolic Diseases.

WILLIAM E. TROUT, JR., BOX 168, UNIVERSITY OF RICHMOND

PSYCHOLOGY SECTION

The Section program for the annual Academy meeting on May 11 at Lynchburg contained 21 papers, the largest number in the history of the Psychology Section. Seven colleges and universities of the state were represented on the program. Elected as Section officers for 1951-52 were Mr. A. W. Hurd, Medical College of Virginia, as Section Chairman, and Mr. S. B. Williams, College of William and Mary, as Secretary-Treasurer.

Mr. W. M. Hinton of Washington and Lee University was elected Treasurer of The Southern Society for Philosophy and Psychology at Roanoke on March 24. Mr. D. M. Allan of Hampden-Sydney College is the Society Secretary.

Dr. Reuben Horlick, Clinical Psychologist at Walter Reed Hospital, has opened an Arlington, Virginia office (3219 Columbia Pike) for private practice of clinical and consulting psychology.

Lieutenant Richard Wienke reported for active duty at Fort Eustis, Virginia during April. Lieutenant Wienke will be doing psychological research for the Army Transportation Corps.

From July 16 through July 20, an H-T-P- Workshop will be conducted at the Lynchburg State Colony by the Chief Psychologist, John N. Buck.

Mr. Emanuel Hammer of Brooklyn, New York, has been appointed as Psychologist B. at Lynchburg State Colony, effective July 1. Mr. William Dakos of Fairmont, West Virginia will become a Senior Interne at the Colony on July 1.

On the summer school staff in Psychology at the University of Virginia will be Mr. W. M. Hinton of Washington and Lee, Mr. R. T. Sollenberger of Mount Holyoke College, and Mr. R. C. Wingfield of Converse College. Mr. Sollenberger and Mr. Wingfield are former University of Virginia graduate students in Psychology.

RICHARD H. HENNEMAN, UNIVERSITY OF VIRGINIA

STATISTICS SECTION

On May 4, Mr. R. A. Bradley was elected to active membership, Messrs. G. W. Suter, G. J. Lombardi, and R. C. Rhodes to associate membership in the Virginia Polytechnic Institute Chapter of the Society of Sigma Xi.

Mr. M. E. Terry received his Ph.D. in Mathematical Statistics at the University of North Carolina.

Among the seminar speakers for the Statistical Summer Session at the Virginia Polytechnic Institute will be Mr. Lee Crump from Rochester University and Mr. Walter A. Hendricks of the United States Department of Agriculture. Some of the possible speakers will include Mr. Allan W. Kimball and Mr. E. G. Olds. Mr. W. S. Flory and the students of the Blandy Experimental Farm will be guests of the Summer Session on August 17 and 18.

MILTON E. TERRY, VIRGINIA POLYTECHNIC INSTITUTE

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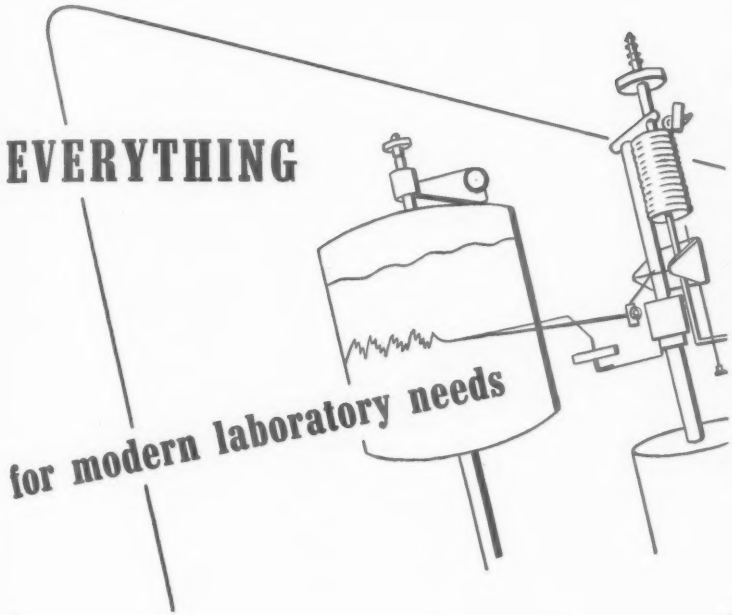

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ERRATA

In the Near Balance Rectangular Lattices by Boyd Harshbarger, Vol. II, No. 1, formulas on Page 19 should be changed to read

CONSTANTS

Set I

$$\frac{(W-W')\ (kB_{11}-T_{11})}{k^2\ [\ (k-2)W+W']} = C_{11}$$

Set II

$$\frac{(W-W')\ (kB_{21}-T_{21})}{k^2[\ (k-2)W+W']} = C_{21}$$

Set III

$$\frac{(W-W')\ (kB_{31}-T_{31})}{k^2[\ (k-2)W+W']} = C_{31}$$

Set h

$$\frac{(W-W')\ (kB_{h1}-T_{h1})}{k^2[\ (k-2)W+W']} = C_{h1}$$

These changes of the constants will effect the numerical values in Table IX, page 25.

Formula 11 on page 19 should be changed to read

$$\sqrt{\frac{2}{kw}\left[1+\frac{(k-1)^2}{k^2-k-1}\left(\frac{W-W'}{(k-2)W+W'}\right)\right]}$$